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Summary Report No. 5: Mica and Vermiculite

R.K. Collings and P.R.A. Andrews
Mineral Sciences Laboratories



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R.K. COLLINGS and P.R.A. ANDREWS
Mineral Processing Laboratory

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by

R.K. Collings* and P.R.A. Andrews**

Abstract

Mica is a group name for a number of hydrous aluminosilicate minerals, such as muscovite, phlogopite, biotite and lepidolite. Muscovite and phlogopite are the principal commercial micas.

Muscovite of commercial interest occurs in sheet and flake form associated with quartz and feldspar in pegmatites. Phlogopite occurs in sheet and flake forms in basic ferromagnesian rocks. Deposits of particular interest occur in eastern Ontario and southeastern Quebec, although occurrences have been noted in several other provinces. There is only one producer of mica in Canada, Suzorite Mica Products Inc., a division of Lacana Petroleum Limited, which operates a deposit of phlogopite mica in Suzor Township, Quebec. The bulk of production is exported to the United States, Japan and Europe. There is no current production of muscovite in Canada; our limited requirements are met by imports from the United States, France and India.

Mica has several unique properties, that is, uniform basal cleavage, high dielectric strength, toughness and flexibility, which have resulted in its broad use in electric and electronic applications. Other uses include filler and strengthener in paint and plastics, and as a substitute for asbestos in joint-filling compounds.

Mica may be processed and used in the dry-ground, water-ground and micronized form. Unique techniques are being developed for treating mica flakes, such as acid leaching and surface coating, to extend the use of mica, particularly in plastic composites.

Vermiculite closely resembles mica but differs in one important aspect: it expands on heating to make a lightweight product that is useful as an insulator in building construction and as a lightweight aggregate in concrete. There is no production of vermiculite ore in Canada; however, imported crude vermiculite is expanded at several Canadian plants for insulation and concrete applications.

Mica and vermiculite processing and beneficiation have been studied extensively by CANMET during the past 50 years. Beneficiation studies of these minerals by CANMET and other organizations are summarized in the appendices.

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RAPPORT SOMMAIRE N° 5 : MICA ET VERMICULITE

par

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Résumé

Mica est un nom collectif désignant des minéraux d'aluminosilicates hydratés, comme la muscovite, la phlogopite, la biotite et la lépidolite. La muscovite et la phlogopite sont les principaux micas d'intérêt commercial.

La muscovite d'intérêt commercial se présente sous forme de lamelles et de paillettes associées au quartz et au feldspath dans les pegmatites. La phlogopite forme des lamelles et des paillettes dans les roches ferromagnésiennes basiques. C'est dans l'est de l'Ontario et le sud-est du Québec que l'on trouve des gisements d'intérêt particulier même si des occurrences ont été relevées dans plusieurs autres provinces. Le seul producteur de mica au Canada est la société Les Produits Mica Suzorite Inc., division des Pétroles Lacana Limitée, qui exploite un gisement de phlogopite dans le canton de Suzor au Québec. L'ensemble de la production est exporté vers les États-Unis, le Japon et l'Europe. La muscovite n'est pas actuellement produite au Canada; on répond aux besoins limités par des importations des États-Unis, de la France et de l'Inde.

Le mica possède plusieurs propriétés particulières, soit un clivage basal uniforme et une rigidité diélectrique, une dureté et une flexibilité élevées, qui ont contribué à sa large utilisation dans des applications électriques et électroniques. Il est également utilisé comme matière de charge et de renforcement dans les peintures et les plastiques et comme produit de remplacement de l'amiante dans les composés de remplissage de joints.

Le mica peut être traité et utilisé après un broyage à sec, un broyage humide ou une micronisation. Des techniques spéciales sont actuellement élaborées pour traiter les paillettes de mica, c'est-à-dire lixiviation acide et revêtement des surfaces, et ainsi accroître son utilisation, en particulier dans les composites plastiques.

La vermiculite ressemble étroitement au mica mais diffère par un aspect important : elle augmente de volume lorsqu'elle est chauffée devenant un produit léger, utile comme isolant dans la construction et comme granulat léger dans le béton. La vermiculite n'est pas extraite au Canada; cependant, on utilise de la vermiculite brute importée dans plusieurs usines canadiennes pour des applications dans les secteurs des isolants et du béton.

Au cours des cinquante dernières années, le traitement et l'enrichissement du mica et de la vermiculite ont fait l'objet de nombreuses études par CANMET. Les études sur l'enrichissement de ces minéraux, réalisées par CANMET et d'autres organismes, sont résumées dans les annexes.

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INTRODUCTION

A CANMET survey of Canadian industrial mineral producers (1) identified a number of problems specific to the industry as well as potential opportunities for further development and expansion. The response to this survey and subsequent discussions with industry and government specialists identified a requirement for information in a number of areas. These areas included mineral deposits, processing, beneficiation studies and new developments, as well as information on product specifications and potential markets for Canadian industrial minerals.

The response to this requirement was a decision to compile related information on file at CANMET and, as available, from provincial government offices and the private sector in a series of summary reports on a number of industrial minerals. The information for each mineral pertains to mineral occurrences, deposits of specific interest, current activities, product uses and specifications, process technology and summaries of past R&D on specific deposits by CANMET and others. This report, *Summary Report No. 5: Mica and Vermiculite*, is the fifth in the series; the first four are Barite, Celestite, Fluorite, and Silica.

MICA

Mineralogy

Mica is the generic name for a number of hydrous aluminosilicate minerals that occur in a variety of forms and colours, depending on inherent chemical properties and mineralogical compositions.

There are four principal minerals in the mica group:

- muscovite - potassium mica, a colourless to pale green or ruby variety;
- phlogopite - magnesium mica, a dark brown or amber variety;
- biotite - magnesium, iron-rich mica, a black or dark green variety; and
- lepidolite - lithium mica, which is lilac.

The first two minerals, muscovite and phlogopite, are the important commercial varieties. Typical chemical compositions of muscovite and phlogopite are reported in Table 1.

Table 1. Typical chemical compositions of muscovite and phlogopite (2, 3)

Oxide or element	Muscovite (South Africa)	Phlogopite (Suzor, Quebec)
SiO ₂	46.90	40.7
Al ₂ O ₃	31.80	15.8
Fe ₂ O ₃	4.39	8.9*
MgO	0.60	20.6
CaO	0.05	-
Na ₂ O	0.70	0.5
K ₂ O	10.50	10.0
H ₂ O	4.47	3.0
F	-	2.2
BaO	-	0.5
TiO ₂	0.05	0.4
Cr ₂ O ₃	-	0.2
NiO	-	0.3
V ₂ O ₅	-	<0.1
P ₂ O ₅	-	<0.1
S	-	<0.1

*FeO

Muscovite typically occurs in acid igneous rocks, such as granites, gneisses and schists, whereas phlogopite more commonly occurs in association with basic magnesium rocks such as pyroxenites, metasedimentary crystalline limestones, peridotites and dunites.

Muscovite of commercial interest is usually associated with quartz and feldspar in granite pegmatites, where the mica may occur as massive crystals measuring from 1 m in diameter down to minute flakes. Pegmatites are the source of sheet, flake or scrap muscovite mica, the latter two products being much smaller in particle size and frequently recovered as a co-product in the production of sheet mica.

Phlogopite is recovered from the noted basic ferromagnesian rock types as flake or scrap mica. Larger sheet phlogopite mica is somewhat less common than sheet muscovite.

Flake or scrap mica is also recovered as a secondary mineral in the production of clay, feldspar, spodumene and certain metallic minerals.

Biotite or black mica commonly occurs in association with pegmatite dykes. The high iron content and consequent low dielectric strength, as well as hardness and poor splitting characteristics, limit its use and value.

Lepidolite or lithium mica, also associated with pegmatites, is much less common than biotite, but like biotite, has poor splitting characteristics and limited value for use as sheet mica.

Deposits

Muscovite

Muscovite occurs at many locations throughout Canada, notably in Quebec, Ontario and British Columbia.

Spence (4) reports that many of the more important muscovite occurrences in Quebec are in the Saguenay district, on the north shore of the St. Lawrence, particularly in the townships of Bergeronnes, Tadoussac and Escoumains. Occurrences are also noted in various counties including Argenteuil, Berthier, Charlevoix, Chicoutimi, Derry, Labelle, Papineau, Portneuf, Témiscamingue, West Portland and Villeneuve. Shaw (5) notes occurrences in several additional counties including Abitibi, Dubuc and Saguenay.

Ontario occurrences of muscovite are reported in Lanark, Leeds, Frontenac, Lennox and Addington, Renfrew, Hastings, Haliburton and Peterborough counties, and in Nipissing, Parry Sound, Sudbury, Lake of the Woods and Rainy River districts (4). Occurrences are also noted in various townships, including Calvin, Canney, Chapman, Chisholm, Christie, Clarendon, Davis, Deacon, Hungerpond, Kaladar, Lennox, Mattawa, McKonkey, Ohig and Sheffield (5).

Muscovite occurrences in British Columbia are reported at Fort Grahame, Big Pond (Columbia River), Tête Jaune and near Yellowhead Pass (4, 5).

Phlogopite

Occurrences of phlogopite in Canada are numerous, and many occurrences, particularly those in Quebec and Ontario, were mined at the turn of the century.

Active mining of phlogopite mica in Quebec was largely confined to the region of the Lièvre and Gatineau rivers, north of Hull, particularly in the townships of Templeton, Wakefield, Hull and Portland. Occurrences were also noted in Pontiac, Argenteuil and Montmorency counties (4). Shaw (5) further identifies phlogopite occurring in Gatineau, Labelle, Laviolette and Montcalm counties. The Blackburn Mine located in Templeton Township, Papineau County, was one of the larger producers of mica in Canada in the early 1900s.

The chief occurrences of phlogopite in Ontario are located in the area immediately north of Kingston and extending toward Perth and Smiths Falls. This area encompasses all or portions of Frontenac, Lanark, Leeds, Carleton, Haliburton and Hastings counties. The Lacy mine, probably the largest mica operation in Canada in the early 1900s, was located in Loughborough Township, Frontenac County (4).

Biotite and Lepidolite

Spence (4) notes the occurrence and minor production of several other varieties of mica including biotite and lepidolite. Biotite was reported in the Saguenay district of Quebec, and in the Frontenac, Hastings, Haliburton and Nipissing districts of Ontario. Lepidolite is associated with lithium-bearing pegmatites in Wakefield Township, Quebec, and in the Bernic Lake area of Manitoba. Mica occurrences and deposits are noted on the map in Figure 1.

The excellent reference work *Mica*, by H.S. Spence (4), provides more detailed information and precise locations of mica deposits and occurrences.

Mining

Muscovite and phlogopite are mined as sheet, flake or scrap mica. Sheet mica occurrences are pockety in nature, the large crystals or books being scattered somewhat indiscriminately throughout the host rock. Flake or scrap deposits are composed of more finely divided mica with the flakes being more uniformly disseminated throughout the deposit.

The sporadic distribution of sheet mica crystals, or books, in pegmatite host rock severely restricts mining methods. Deposits of interest are usually trenched or test pitted to obtain general information on the location and occurrence of the mica crystals. Following this, the mica books are carefully removed and the pit or trench is enlarged by a gopher-hole system of mining to locate and recover adjacent crystal. A relatively deep deposit will require a shaft and exploratory cross cuts and drifts to locate additional mica.

Sheet mica mines are usually small-scale operations and during mining, care must be taken to avoid drilling through good mica crystals. If explosives are required, only low-velocity, 40% dynamite is used to free a pocket of mica. Only a few holes are shot at one time to avoid the destruction of the available mica sheet.

Large-scale quarrying methods are used to develop deposits that are operated for the extraction of small particle size mica and possible co-product minerals (6).

Flake or scrap mica, being more uniformly distributed throughout the host rock, may be evaluated by test pits or diamond drilling and the ore may be recovered by conventional open-pit methods or by hydraulic mining.

Processing (6)

Processing methods vary depending on whether the mica is in sheet or flake form and on the ultimate end use.

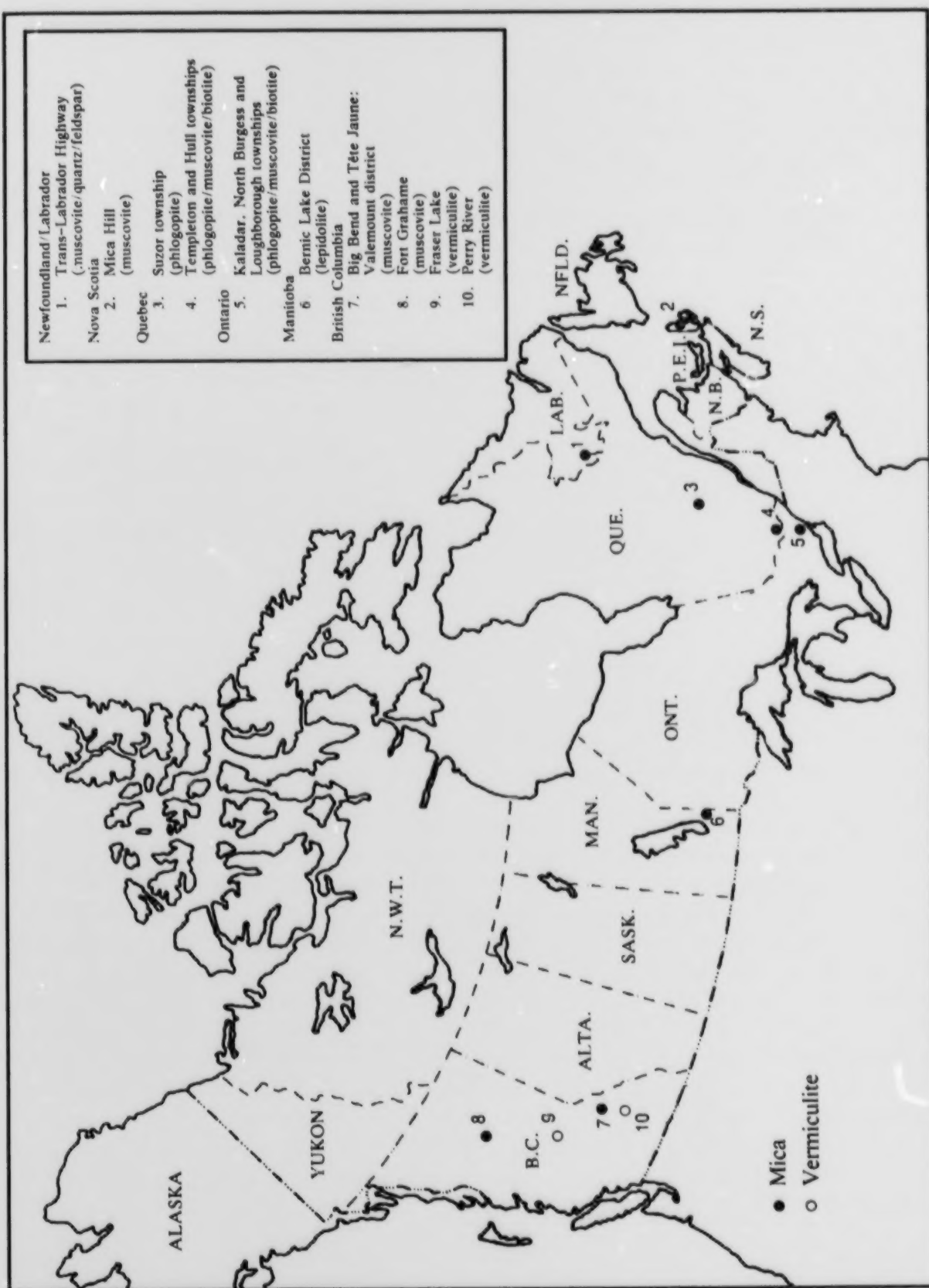


Fig. 1 - Principal mica and vermiculite deposits in Canada

Preparation of sheet mica for market requires cobbing to remove adhering dirt, rock and defective mica. The cobbled mica is then rifted into suitable thicknesses, and any major flaws are removed. The mica produced in this manner is broadly classified as untrimmed mica and scrap mica. The mica is then trimmed with a knife to a bevel edge to remove broken and ragged edges, loose scales and other major imperfections.

Scrap mica resulting from mining, trimming, or fabrication of sheet mica is bagged and sold to mica grinders without any additional processing. Flake mica is recovered from pegmatites, schist or other rock by crushing and screening the host rock, and beneficiated by flotation or dry and wet gravity concentration methods. The recovered mica is dried and screened at 1.2 mm to separate the minus 1.2 mm fraction, which goes to either waste or further recovery. Any oversized mica is passed through a rolls crusher and transported to a dry grinding operation.

Raw material for ground mica production is obtained from sheet mica processing operations, from crushing and milling of schists, or as a co-product of kaolin or feldspar production. Buhr mills, rod mill and high-speed hammer mills have been used for dry grinding mica. The mills are in closed circuit with an air separator, which returns any oversized mica for additional grinding. The mill discharge is screened into various sized fractions and bagged for marketing. The ground mica yield from beneficiated scrap averages 95 to 96% of the weight of scrap.

Flotation

Mica flotation was studied extensively by the U.S. Bureau of Mines in the mid-1960s. Two methods, acid-cationic and alkaline-anionic cationic, were successfully developed for the recovery of mica from various ore types (7).

The acid-cationic method allows for the recovery of mica as coarse as 1.2 mm; however, the ore must be completely deslimed at 100 to 75 μm . The ground ore is then conditioned with sulphuric acid and a quartz depressant at 40 to 45% solids, and optimum mica flotation is obtained at pH 4.0 using dodecylamine acetate collector in combination with fuel oil. The cationic method has been used for the recovery of mica from pegmatite ores. A flowsheet depicting this method is shown in Figure 2.

The alkaline anionic-cationic method of mica flotation was developed for the recovery of mica when slimes are present. The process requires conditioning the finely ground ore at 40 to 45% solids with sodium carbonate and calcium lignin sulphonate at pH 8.0 to 10.5, and floating the mica with a combination of oleate and amine-type collectors. Mica as coarse as 840 μm can also be recovered by this method, and separation is not greatly sensitive to pH. Continuous treatment of ore using the alkaline anionic-cationic method is outlined in the process flowsheet shown in Figure 3.

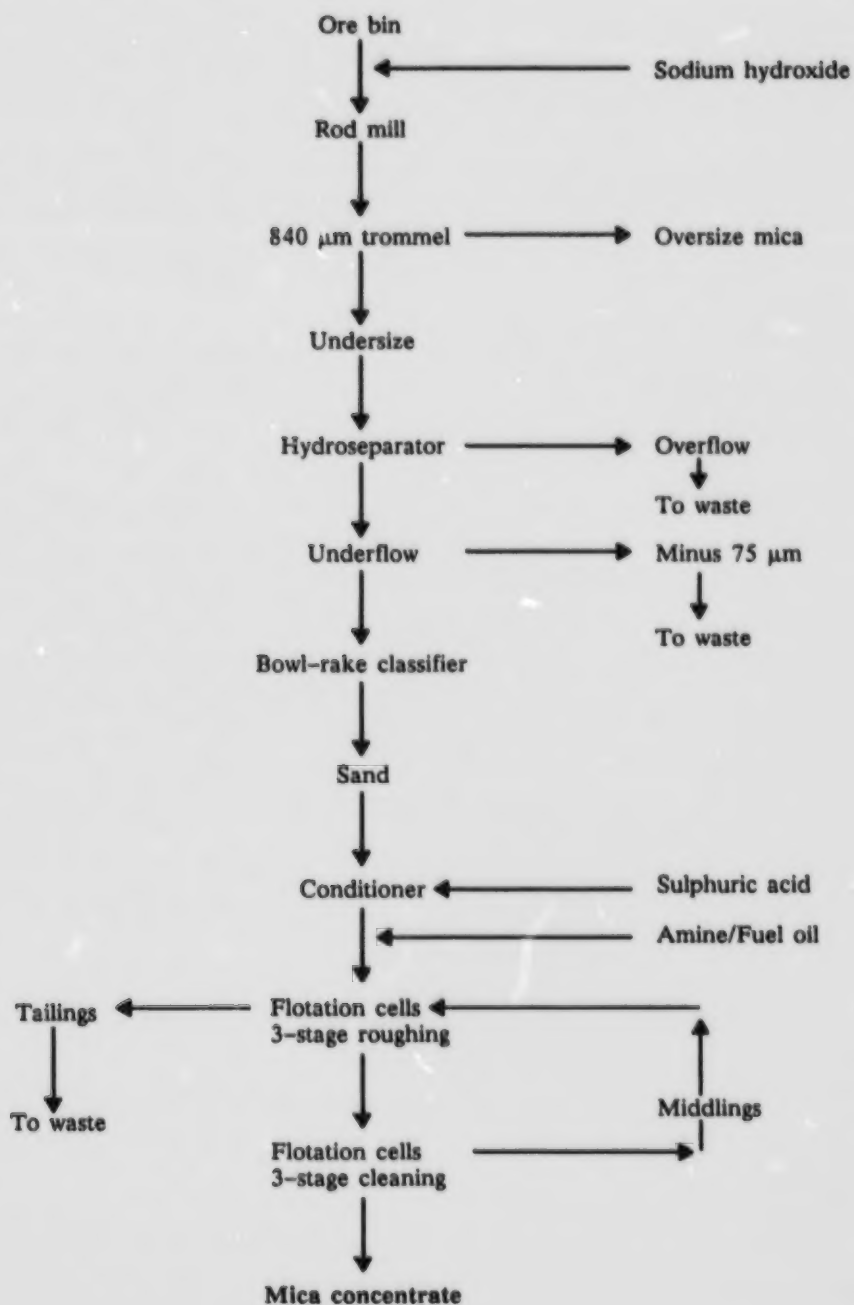


Fig. 2 - Flowsheet for recovery of mica using the acid-cationic method (7)

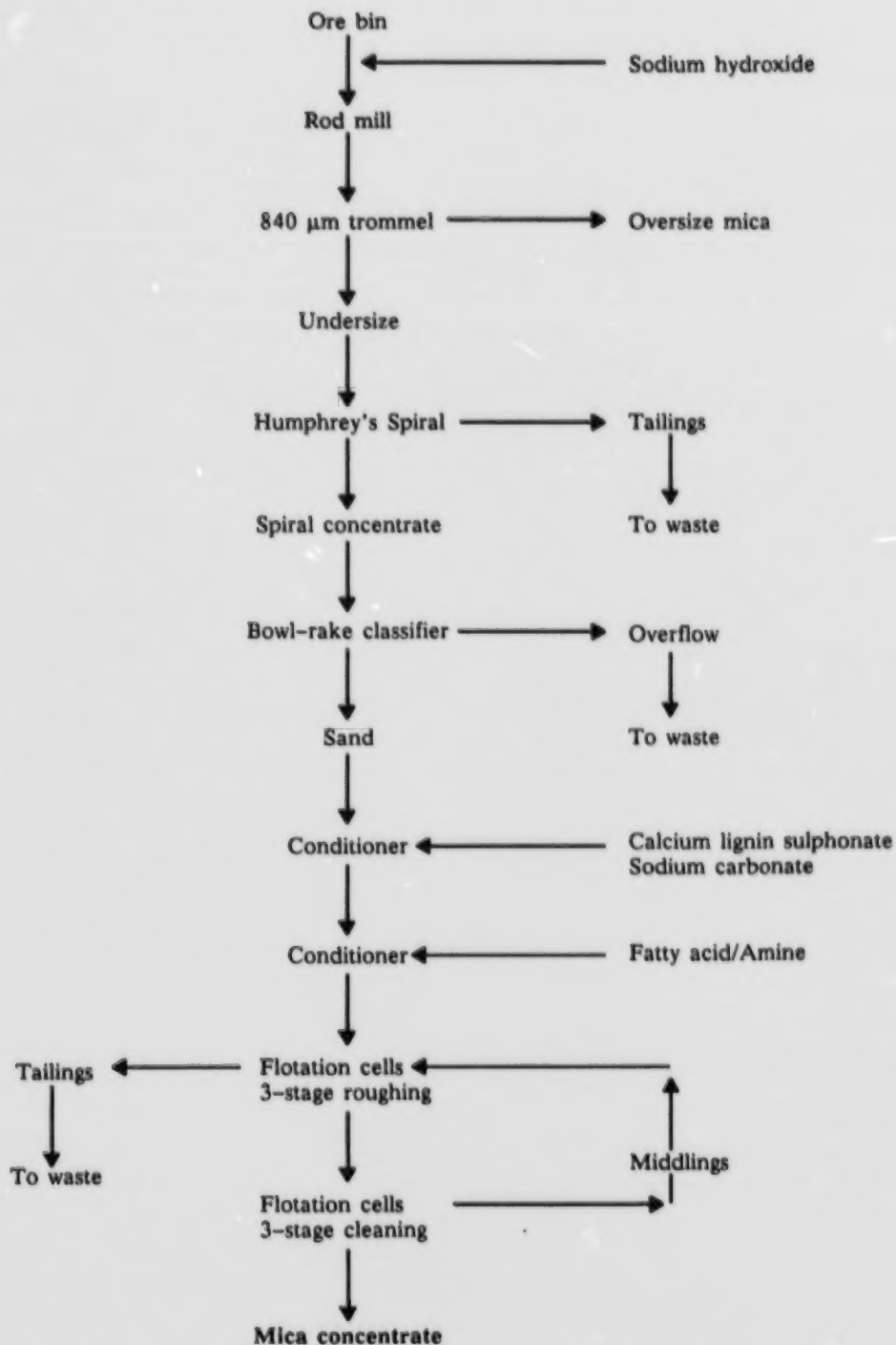


Fig. 3 - Flowsheet for recovery of mica using the alkaline anionic-cationic method (7)

Grinding

Certain filler-extender applications for mica, such as rubber, paint and plastic, require a very finely ground product. Two methods of grinding are typically employed: traditional wet grinding and fluid-energy grinding.

Wet-ground mica is produced in chaser-type or edge-runner mills to preserve the sheen or lustre of the mica. This type of mill consists of a cylindrical steel tank that is lined with wooden blocks laid with the end grain up. Wooden, ceramic or metal-faced rollers are generally used, which revolve at a slow rate of 15 to 30 rpm. Hopper-fed scrap and water are slowly mixed to form a thick paste. When the bulk of the mica has been ground and delaminated to the desired size, which requires 5 to 8 h depending on feed size, the discharge is washed from the mill into settling tanks. The ground mica overflow is dewatered by centrifuging and steam drying. The final product is obtained by screening on enclosed multiple deck screens (6).

"Micronized" mica is produced in a jet mill or micronizer. This ultrafine material is produced in a disintegrator that has no moving parts, but uses jets of high-pressure superheated steam to reduce the mica to size ranges of 10 to 20 μm and 5 to 10 μm . The Majac mill is another device for dry grinding mica using fluid energy. A screw conveyor feeds mica continuously into a chamber containing two horizontal, directly opposed jets. The particle size of the final product can be controlled over a broad range of sizes (6).

Ground mica, in addition to being very fine, has a high aspect ratio (diameter: thickness), which imparts desirable characteristics such as improved flexural strength (advantageous in rubber and plastic formulations) and improved coverage and hiding characteristics in paint and varnishes.

Synthetic Mica

Numerous micas can be synthesized. The following are examples of synthesized fluor-phlogopites and fluor-muscovites.

Normal

- fluor-phlogopite, $\text{KMg}_3\text{AlSi}_3\text{O}_{10}\text{F}_2$;

Other

- boron tri-silicic, $\text{KMg}_3\text{BSi}_3\text{O}_{10}\text{F}_2$;
- tetra-silicic, $\text{KMg}_2^{1/2}\text{Si}_4\text{O}_{10}\text{F}_2$;
- lithium tetra-silicic, $\text{KMg}_2\text{LiSi}_4\text{O}_{10}\text{F}_2$;
- barium di-silicic, $\text{BaMg}_3\text{AlSi}_2\text{O}_{10}\text{F}_2$; and
- barium lithium tri-silicic, $\text{BaMg}_2\text{LiAlSi}_3\text{O}_{10}\text{F}_2$.

Normal

- fluor-muscovite, $\text{KAl}_2\text{AlSi}_3\text{O}_{10}\text{F}_2$;

Other

- fluor-paragonite, $\text{NaAl}_2 \cdot \text{AlSi}_3\text{O}_{10}\text{F}_2$;
- fluor-lithium muscovite, $\text{KLi}_1^{1/2}\text{Al}_1^{1/2} \cdot \text{AlSi}_3\text{O}_{10}\text{F}_2$; and
- fluor-polyolithionite, $\text{KLi}_2\text{Al} \cdot \text{Si}_4\text{O}_{10}\text{F}_2$.

Few micas of the muscovite type have been synthesized, and none of these has been crystallized from a melt (8).

Synthetic mica is manufactured in a furnace consisting of a shell to hold the batch and a pair of graphite electrodes positioned to generate heat in the interior of the batch. A variable transformer controls the supply of alternating-current electricity to the electrodes.

The batch for normal fluor-phlogopite consists of a properly proportioned, dry, pulverized, uniform mixture of potash, feldspar, potassium silicofluoride, magnesia, alumina and silica. The batch is usually compounded to have fluoride present in excess of stoichiometric proportions. Although the fluor-phlogopite melt is an excellent electrical conductor, the cold batch is a good insulator, so that a small-diameter graphite resistor connecting the vertical electrodes is used to start the melting. The resistor is consumed by oxidation after several hours of operation, but not before a small pool of melt connects the electrodes. Heating is continued until the melt has advanced almost to the steel shell. Thus, the raw and partially reacted batch remaining around the melt serves as the container for the melt, which has a temperature of about 1360°C . The melt is permitted to cool slowly and, after several days, the crystallized melt is broken with pavement breakers, and the large crystals are recovered by hand sorting. The finer mica is crushed and ground (6).

Micanite

Built-up mica or micanite is made from mica splittings. The splittings are arranged either mechanically, using air suction, or by hand so that they overlap in layers of uniform thickness. Alternate layers of mica and a cementing agent such as shellac are built up and bonded together by the application of heat and pressure. The micanite is then further fabricated in the same manner as natural block mica (9).

Reconstituted Mica

Reconstituted mica is a paper or a mat made from high-quality scrap. This is partially exfoliated by heating. The mica flakes are then fed as pulp to a modified paper-making machine, which produces a continuous sheet of mica paper. The mica paper is then impregnated with a binder and cut into required lengths (9).

Glass-Bonded Mica

Glass-bonded mica is made from a mixture of ground mica and powdered glass. The mixture is pressed into moulds and heated to soften and anneal the glass. Lead borate or borosilicate glasses,

which have melting temperatures below that at which mica begins to break down chemically, are used. The moulded components can be fabricated by grinding, cutting or drilling (9).

Uses and Specifications

Muscovite is the form of mica that is in greatest industrial demand because of its dielectric strength, perfect basal cleavage, toughness and elasticity, chemical inertness, thermal stability up to about 500°C, and its transparency and silvery lustre. Muscovite is normally superior to phlogopite and biotite, but phlogopite is substituted where thermal stability up to about 850 to 1000°C is required.

The principal commercial types of mica, muscovite and phlogopite, are used in a variety of different forms as follows:

- sheet mica
- flake or scrap mica
- ground mica
- synthetic mica
- built-up mica or micanite
- reconstituted mica or mica flakes

Sheet Mica

Sheet muscovite mica is used in electrical and electronic applications principally because of its high dielectric strength, which makes it an excellent electrical insulator. Electrical equipment incorporating mica components includes condensers, transformers, small heating elements, rheostats, fuses, incandescent bulbs, thermionic devices and certain types of coils. In generators, it is used for commutator and armature insulation. There are also more specialized uses for mica, such as in X-ray apparatus and acoustic equipment.

The market for sheet mica has been in a state of decline in recent years because of the introduction of printed circuits and silicon chips; however, several new products are being developed. These include special optical filters, retardation plates in helium-neon lasers, gap separators in computer recording heads, and gold- and silver-coated sheeting for communications devices (5). Sheet mica is graded according to thickness: blocks must be thicker than 0.18 mm, films between 0.0206 and 0.1028 mm, and splittings approximately 0.0028 mm. The specifications for sheet mica comply with the standards of the American Society for Testing and Materials (ASTM). Designation ASTM-D351-62 specifies quality according to stain, inclusions and imperfections. Designation ASTM-D2131-65 provides the required characteristics for mica product manufacture. Designation ASTM-D748-59 defines the requirements for electrical, physical and visual properties of the mica sheets used in capacitors.

Nonelectrical uses for sheet mica include gauge glasses for high-pressure steam boilers, furnace windows, and transparent diaphragms for oxygen-breathing equipment and goggles (9).

Flake Mica

Finer sizes of flake or scrap muscovite are used to manufacture micanite, mica paper, glass- and phosphate-bonded mica. These products are less expensive than natural sheet mica and are substituted in various products to reduce their cost.

Ground Mica (9)

Ground mica is marketed in three forms: dry, wet ground and micronized. Dry grinding is a simple and relatively inexpensive process and is used mostly to produce material in the 1.2 mm to 150 μm size range. Dry-ground mica is used as a filler, for example, in the manufacture of rubber, plastics and insulating boards. It can also be utilized as a surface coating for asphaltic roofing materials. This surface coating prevents the adhesion of adjacent asphalt surfaces of shingles or roll roofing. Furthermore, as a consequence of its platy nature, mica is not appreciably absorbed by freshly made asphalt products and therefore acts as a continuous weatherproof coating. Oil-well drilling muds use coarser grades of dry-ground mica (1.2 mm to 420 μm) as a sealant because of its platy structure. Finer grades of dry-ground mica are used as a pigment extender in paint. Surface coatings of dry-ground mica are used as a flux coating on welding rods, on cores and moulds for metal casting, on electric cables, on concrete, tile and stucco surfaces, on wallpaper and as artificial snow on Christmas cards. Dry-ground mica is the major constituent used in the manufacture of some reconstituted mica components. Lesser uses are as an annealing agent in metal treatment, as an absorbent for explosives and disinfectants, and in fire extinguishers, acoustic products, adhesives and lubricants. Dry-ground mica is an effective thermal insulator but, owing to its higher specific gravity, it is not as suitable as expanded vermiculite for cavity wall insulation.

The dry grinding process is unsuitable for producing the finer grades of ground mica because the characteristic laminar crystalline structure of the mica flakes tends to be destroyed. When it is desirable to retain the form of the mica flakes in finely comminuted grades, a wet-grinding technique is used. Even the finer grades of commercial mica powders retain the laminar form when produced by the use of steam micronizers.

Wet-ground or micronized mica is particularly important in manufacturing paint. Material in the range 90 to 45 μm is superior to dry-ground mica as a pigment extender because it increases the resistance of the paint to weathering and contraction. A more silvery appearance can be imparted to wallpaper by the use of wet-ground rather than dry-ground mica. Although more expensive than dry-ground mica, the wet-ground or micronized commodity is specified as a filler and mould lubricant in the manufacture of some specialized rubber and plastic products. Wet-ground mica can be used as an efficient antisticking, antifriction powder between the inner tubes and casings of tires. Certain special greases used as lubricants or soft packings require an alternative to graphite, and in these cases wet-ground mica may be suitable as a substitute.

A summary of uses for ground mica related to specific properties is reported in Table 2. Typical particle size requirements for several uses are summarized in Table 3.

Table 2. Ground mica uses related to specific properties (7)

1. Dry-ground

- | | |
|-----------------------|--|
| plastics | - mica improves elasticity, flexural and tensile strength. |
| joint cement | - mica improves workability and finish, and reduces cracking. |
| oil-well drilling mud | - mica serves to seal off openings and fractures encountered when drilling through porous or fractured formations. |
| surface coatings | - medium to finer-flake are used in stucco coatings for housing, in textured stone and roof paints, and in textured plasters for interior use. |
| welding electrodes | - mica is used in electrodes to control flux and slag characteristics. |

2. Wet-ground

- | | |
|--------------|--|
| rubber tires | - mica is used as a dusting and release agent in the manufacture of tires, and as a filler in the rubber to reduce porosity and shrinkage during moulding. |
| paint | - mica in paint improves application and reduces chalking, fading, shrinking and cracking. |

Table 3. Particle size distribution of ground mica products (7)

Size (μm)	Dry-Ground Mica				Wet-Ground Mica	Micronized Mica
	Oil Wells	Joint Cement	Welding Electrodes	Plastics	Rubber Grade	Paint Grade
% finer than						
6400	100	-	-	-	-	-
2800	80	100	-	100	-	-
1200	30	98	-	98	-	-
500	10	50	-	60	-	-
355	-	10	-	40	100	-
250	-	-	100	10	99	-
150	-	-	99	-	70	100
105	-	-	95	-	50	99.9
75	-	-	85	-	35	85
53	-	-	75	-	20	80
44	-	-	70	-	5	75
Bulk Density (kg/L)	0.30	0.29	0.26	0.24	0.18	0.22

Current Producer – Suzorite Mica Products Inc.

The only current producer of mica in Canada is Suzorite Mica Products Inc., a division of Lacana Petroleum Limited of Toronto. This company obtains phlogopite from a deposit located in Suzor Township, Laviolette County, 300 km north of Montréal. The deposit is schistose in nature and contains 85% or more of phlogopite. Impurities include 4 to 8% pyroxene, 2 to 6% perthite, and trace amounts of apatite, calcite and chlorite. Ore reserves are estimated at 30 Mt.

The ore is blasted by long-hole drilling in an open pit on an intermittent basis. The blasted ore is excavated by backhoes, loaded into haulage trucks, and transported to a nearby crusher, which reduces the ore to minus 23 cm. The crushed ore is transported to a plant at Boucherville, north of Montréal, for processing.

Ore from the plant stockpile is fed through a grizzly feeder and conveyed to a jaw crusher, which reduces it to minus 50 mm. A gas-fired rotary kiln reduces the average moisture content from 6 to <0.5%. The dried ore is reduced to minus 6 mm in an impact crusher and screened into three different sizes. Material larger than 6 mm is returned to the crusher, whereas minus 6 plus 1.7 mm, and minus 1.7 mm fractions are further processed.

The minus 6 plus 1.7 mm fraction is size reduced to minus 1.7 mm and, together with the minus 1.7 mm fraction from primary sizing, is screened into three sizes: minus 1.7 mm plus 840 μm , minus

840 plus 300 μm , and minus 300 μm . The material then enters a gravity separation air table where the mica is separated from grit.

Undelaminated material is further processed along with special feed streams in specially modified high-velocity pin mills, which lower the bulk density to 0.29 g/mL.

One stream of pure mica is ground in a fluid-energy mill where flakes slice into one another at high-velocity to form the finer grades of finished product. The fluid-energy product ranges from 150 to minus 44 μm in size and may contain as much as 90% minus 44 μm .

About 25 manufactured products are sold through the company's marketing offices in Hunt Valley, Maryland, and field staff in Toronto, Ontario, and Buffalo, New York. The products are used in a variety of applications including plastics, jointing compounds, oil-well drilling muds, caulking and moulding compounds, and coatings (10).

The plant has a capacity of about 35 000 tpa of mica for bulk commodity applications (11).

Trade and Consumption

Domestic consumption accounts for about 25% of Canadian phlogopite mica production. The bulk of the production, 50%, is exported to the United States. Japan and Australia account for an additional 20% and western Europe, 5% (12).

Canada imports ground mica from the United States, mica blocks and sheet from India, and fabricated mica products from the United States, France, India and the United Kingdom. Imports of ground block and sheet mica in 1987 were 2204 t (Table 4).

Canada does not have a large consumer market for mica products. Gypsum caulking products and paint account for more than 90% of mica consumption; rubber, plastics and drilling mud industries account for the remainder. Consumption data are reported in Table 5.

Current Interest and Developments

There is a continuing strong demand for the further development and use of mica in plastics and other products to improve performance, and as a substitute for asbestos. Mica is finding increasing application as a substitute for asbestos in drywall sealing compounds, in fire-resistant building panels, in brake linings and in other specialty products. There is a renewed interest in muscovite mica for use as a filler-extender-reinforcer in plastics and paints (21, 22), and as an electrical insulator in electronic and electrical equipment.

Suzorite and others (13-18) have developed techniques for coating mica with silane and other specialty coatings, which help to promote bonding of the mica in plastic composites.

Table 4. Canadian mica imports, 1986-87

	1986		1987	
	(tonnes)	(\$000)	(tonnes)	(\$000)
Mica in blocks, films, sheets and ground				
United States	2 174	878	2 186	900
India	0	0	18	25
Subtotal	2 174	878	2 204	925
Fabricated mica				
United States	-	2 866	-	2 218
France	-	686	-	489
India	-	196	-	410
United Kingdom	-	1	-	170
Switzerland	-	0	-	0
West Germany	-	0	-	0
Hong Kong	-	0	-	0
Subtotal		3 750*		3 287
Total rough, sheet, ground and fabricated mica	-	4 628	-	4 212

Sources: Energy, Mines and Resources Canada and Statistics Canada

- not available

*Because figures have been rounded, summations may not correspond to the totals indicated.

Table 5. Reported consumption¹ of mica in Canada, 1986-87

	1986	1987
	(tonnes)	(tonnes)
Gypsum products	2 764	4 398
Paint and varnish	166	124
Other products ²	319	269
Total	3 249	4 791 ³

¹ Reported from EMR survey on the consumption of nonmetallic minerals by Canadian manufacturing plants.² Includes chemicals, primary steel and miscellaneous products.³ Increase in number of companies being surveyed.

Suzorite has developed another product, E-Mica, which is a nickel-coated mica for use in plastics for electronic equipment to shield sensitive areas, such as computer circuitry, from electromagnetic radiation. Nickel-coated mica has both reinforcing properties and good electrical properties (19). A mica ceramic attenuation material capable of absorbing high-power microwaves has been developed from synthetic fluoromica (20).

In eastern Ontario, muscovite deposits in the vicinity of Kaladar are being investigated by several companies including Lacana Petroleum Limited, Steep Rock Resources, and Kozumi Limited of Japan. Pegmatite-associated muscovite deposits occurring in the vicinity of the Trans-Labrador highway are being studied by the Newfoundland Department of Mines, St. John's, for possible use as flexible, heat-resistant electrical insulators. The Nova Scotia Department of Mines and Energy, Halifax, recently resampled a small, pegmatite-associated muscovite deposit at Mica Hill, 10 km west of Neil's Harbour in northeastern Cape Breton.

CANMET has participated in a number of mica studies, particularly with the Newfoundland and Ontario governments, and with Steep Rock Resources. Recent government-assisted studies on mica markets included those relating to Quebec phlogopite (suzorite) and Manitoba lepidolite.

Mica is expected to experience growth in plastics, in drywall compounds and in paint. Filler applications are relatively minor. The total North American filler market is estimated at 90 000 tpa, of which about half is consumed in established markets.

Future Markets

Changing trends in the usage of mica can be identified. The use of sheet mica is becoming restricted to those essential applications that make use of a combination of several of its properties that cannot be collectively matched by substitutes. When only one distinctive property of mica is required, for example, transparency or electrical resistance, sheet mica is no longer used. Even in applications where sheet mica has not been replaced, it is apparent that there has been a shift towards the use of lower grades and built-up mica rather than the natural material. In the future, built-up mica, made from sheet mica splittings, may itself be replaced by reconstituted mica made from scrap or flake (9, 23).

Alternative materials such as polyamides, polyesters, polystyrene, alumina, steatite ceramics, fused quartz and silicon rubber are making inroads as substitutes for sheet mica.

The total annual world production of mica is small compared with other minerals. Relatively small tonnages of mica are used in a large number of technical products in widely dispersed markets around the world.

Despite the threat of substitutes, the traditional outlets of mica products are considered relatively stable with limited growth within the construction, automotive and oil industries (2).

Prices

The least expensive grade, scrap mica, sells for U.S. \$150 to \$200 per tonne. Dry-ground mica sells for U.S. \$300 to \$400, and micronized mica for U.S. \$400 to \$550. Water-ground mica commands a higher price at U.S. \$700 to \$1000. The highest prices, however, are for surface-treated grades.

VERMICULITE

Mineralogy

Vermiculites are platy, thinly laminated minerals with perfect basal cleavage which closely resemble mica. They differ physically from the micas in that they are dull in lustre, soft, pliable and inelastic, with a surface that is yellow, green, brown or nearly black. Raw vermiculite has a hardness of 1.5 to 3.0, specific gravity of 2.2 to 2.7, and specific heat of 0.2. The most striking difference between mica and vermiculite is that the latter expands or exfoliates by as much as 20 times perpendicular to the cleavage when heated. The name vermiculite, derived from the Latin *vermiculari* (to breed worms), is attributed to this property of exfoliation. There are about 19 varieties of vermiculite, all monoclinic, hydrated, ferromagnesian aluminosilicates (24). Exfoliation occurs when water molecules are expelled on heating the mineral rapidly to temperatures between 800 and 1100°C. The moisture rapidly turns to steam, causing the platelets to separate.

Chemical compositions of vermiculites differ considerably; comparative analyses of three varieties are reported in Table 6.

Table 6. Composition of vermiculites (25)

Oxide or Element	Libby, Montana %	Enoree, S. Carolina %	Palabora, Transvaal %
SiO ₂	38.64	38.66	39.37
MgO	22.68	20.04	23.37
Al ₂ O ₃	14.94	17.36	12.08
Fe ₂ O ₃	9.29	8.45	5.45
FeO	-	-	1.17
K ₂ O	7.84	5.24	-
CaO	1.23	0.75	1.46
Cr ₂ O ₃	0.29	0.50	-
Mn ₃ O ₄	0.11	0.12	-
P ₂ O ₅	trace	trace	-
S	trace	trace	-
Cl	0.28	0.52	-
H ₂ O	5.29	8.71	11.38

Vermiculite is usually associated with basic rocks such as pyroxenite, peridotite, dunite, marble, serpentine and syenite, and minerals such as quartz, feldspar, apatite, kyanite, corundum, biotite, chlorite, phlogopite, asbestos, talc and clay.

Deposits

Vermiculite occurrences are described by Stewart and Strand (26) and discussed in detail in a CANMET report by Wilson (27). A summary of the latter study follows.

There are a number of relatively small deposits of vermiculite in Canada, specifically near Perth, North Bay, Sudbury, Peterborough and Mattawa in Ontario, and near Lac St. Jean and Venosta in Quebec. Larger deposits have recently been reported in British Columbia.

The Canadian deposits investigated are not comparable in grade to those noted in Table 6. Vermiculite, according to Guillet (28), is found in Ontario in basic rocks or coarsely crystalline limestones, all of which appear to have had an original sedimentary origin. In the Perth area, pyroxenites were formed at the expense of marble and, east of North Bay, a coarse hornblende rock occurs as a recrystallized amphibole. Occurrences in relatively unaltered marble are either disseminated throughout the rock or concentrated at dyke contacts. Small syenitic or dioritic dykes are sometimes associated with the development of vermiculite.

Vermiculite may be formed at the expense of phlogopite or biotite. Vermiculitized phlogopite has been found rather uniformly disseminated in both marble and metamorphic pyroxenite in flakes usually less than 6 mm in size. Vermiculitized biotite has been found in amphibolite and biotite schist more or less concentrated in narrow lenses or at dyke contacts. Hydration of either mica variety generally falls short of saturation, so that unaltered and poorly altered mica commonly accompanies the vermiculite.

Deep weathering is a common feature of vermiculite deposits, and where vermiculitization was restricted to the zone of weathering, groundwaters locally enriched in magnesium or calcium ions may have been responsible for the alteration. Vermiculite formed at greater depths is more likely to be of hydrothermal origin.

Vermiculite is generally found in any mica-rich rock that has been highly fractured or otherwise exposed to migrating magnesium-bearing solutions. Consequently, deposits are usually found in carbonate or basic associations where a lime-magnesia environment is assured. The limestone terrain of the Grenville subprovince of southeastern Ontario is therefore especially favourable for vermiculite. Belts of Huronian sediments, and carbonatites associated with alkaline ring complexes, may also host vermiculite in northern Ontario (28).

The only deposits in Canada that were commercially exploited are at Stanleyville, near Perth, Ontario. Northern Vermiculite Limited operated a deposit north of Stanleyville for a short period in the

mid-1950s, and Olympus Mines Limited mined, milled and exfoliated vermiculite from a deposit south of Stanleyville in the mid-1960s. Vermiculites now exfoliated in Canada are all imported from the United States and South Africa (29).

Three recently discovered vermiculite deposits, all reported as being major, were recorded by the British Columbia Ministry of Energy, Mines and Petroleum Resources. They occur in granitic intrusions near Fort St. James and Fort Fraser, and in a carbonatite dyke at Perry River (see map in Figure 1). These deposits are being further investigated by the noted British Columbia ministry (30).

Mining and Processing

Vermiculite ore is recovered by open-pit mining or quarrying. The broken ore is transported to the milling plant where the vermiculite is concentrated and sized using a combination of wet and dry processes, the choice of processes depending on the physical characteristics of the various constituents. The ore is first crushed to liberate the vermiculite flakes; if a coarse flake is required, minimum crushing is necessary to avoid producing excess fines. The books of vermiculite must also be delaminated because flakes that are too thick will not exfoliate properly on heating.

A typical milling flowsheet (2, 31) would involve the initial removal of boulders of diopside and serpentine coarser than 30 cm by passing the ore over a stationary grizzly. The undersize material is passed over a second grizzly to remove plus 15 cm low-grade ore. The undersize material from the second grizzly is passed over a 20 mm screen, and the screen oversize reduced to minus 20 mm in a primary impact crusher. Size reduction can also be accomplished using jaw, cone or rolls crushers, and hammer or rod mills, depending on the crushing characteristics of the ore.

The crushed ore is usually dried to a moisture content of 4% to enable free-flowing ore to be further concentrated before exfoliation.

Vermiculite that is to be exfoliated is first concentrated and sized. This includes a series of operations involving screens, air tables, wet tables, classifiers, jigs, flotation or magnetic separators. The method of concentration depends on physical properties, density and surface area of the components of the ore. Gravity separation is the most common method, but the closer the density of the vermiculite and the gangue, the more difficult the separation.

Vermiculite is concentrated by flotation at 250 to 150 μm , and 150 to 75 μm , using oleic and linoleic acids at concentrations of 200 to 350 mg/L (32). Vermiculite can be separated from biotite and hydrous biotite using magnetic separation (33).

The concentrated vermiculite is finally separated into various size fractions for market applications. The optimum shape of the exfoliated particle is cubic, so that sizing of the raw flake is consistent with preserving this quality. The standard commercial screen sizes are minus 6.7 plus 1.7 mm, minus 3.4 plus 1.2 mm, minus 2.4 mm plus 600 μm , minus 840 plus 210 μm , and minus 300 μm (26). A simplified flow diagram for vermiculite ore processing is shown in Figure 4.

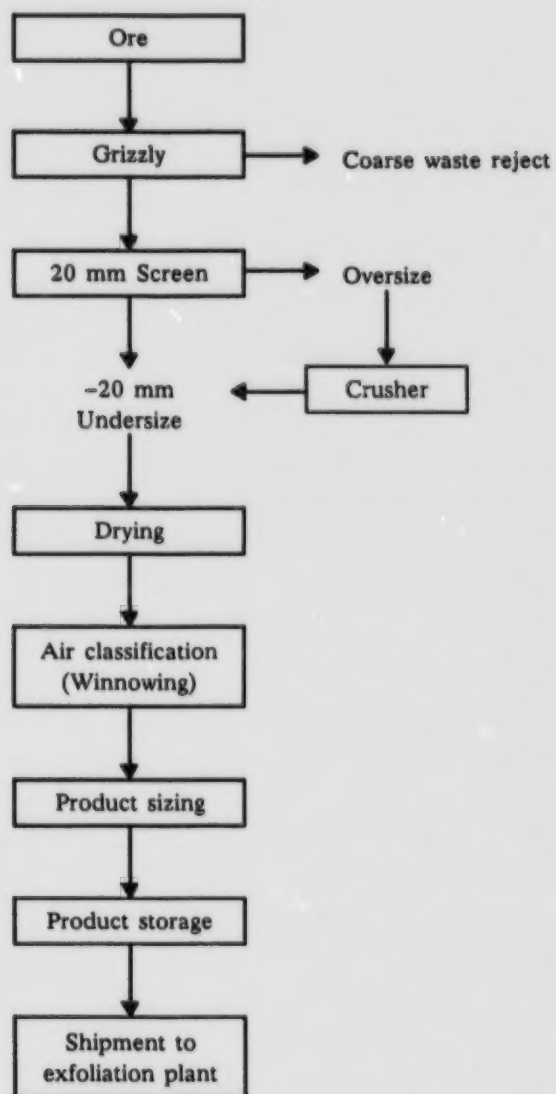


Fig. 4 - Flow diagram for vermiculite ore processing

Exfoliation

Exfoliating plants are situated as close to consumers as possible to reduce transportation costs because of the low weight: volume ratio of exfoliated vermiculite. Exfoliation may be accomplished using a variety of furnaces, but the most common is a vertical furnace 0.9 to 1.2 m² and from 1.8 to 4.5 m high, heated by either gas or oil to a temperature between 850 and 1100°C, although temperatures as high as 1500°C are reported (34).

The crude vermiculite is fed into the upper end of the furnace, where it falls past baffles, which evenly spread the vermiculite for exfoliation. The exfoliation of the vermiculite takes place very rapidly, within 5 to 8 sec; it is immediately cooled to 400°C before leaving the bottom of the furnace.

The thermal capacity of the expanded product at this stage is very low, so that cooling is rapid. By arranging for a delay at this cooled temperature, it is found that expansion of the thicker flakes continues to completion. The material will drop 10 to 12% in weight because of moisture loss.

The theoretical heat required to exfoliate vermiculite is about 1.2 MJ/kg, but most installations require 1.8 to 2.4 MJ/kg. A schematic diagram of a vertical section of a typical furnace is shown in Figure 5.

To reduce the risk of fire or scorching of the packaging for the final product, it is advisable to further cool the freshly expanded material by transporting it on an open metal conveyor belt, from which the lightweight vermiculite can conveniently be lifted by suction to product hoppers. The remaining heavy impurities are run to waste (34).

Vermiculite is customarily sold by volume in paper sacks of 0.11 m³ capacity. The weight of each bag is about 7 kg for the coarse grades and 14 kg or more for the finer ones (34).

Dust Control

There are no known health hazards associated with vermiculite, but the various processes can create considerable dust. However, by ensuring dust-tight covers where movement takes place, the application of suction points, and the conveyance of material by air under negative pressure, the working conditions within the factory can easily be kept within acceptable limits (34).

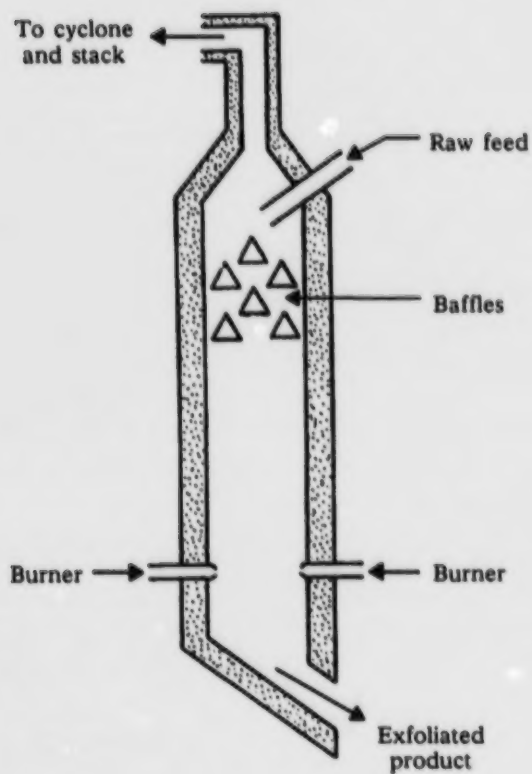


Fig. 5 - Schematic section of a typical vertical furnace for exfoliating vermiculite (27)

Properties and Applications

The significant properties of exfoliated vermiculite include low density, low thermal conductivity, high liquid absorption, high surface: volume ratio, neutral pH, inertness in normal usage and base exchange capacity. It is inert to organic solvents, clean to handle, reflective, rot proof, nonabrasive, odourless, mouldable and nonirritating. Vermiculite is also incombustible and has a high sintering temperature. Typical ranges of properties are:

Loose bulk density (raw)	640 to 960 kg/m ³
Loose bulk density (exfoliated)	56 to 192 kg/m ³
Sintering temperature	1260°C
Melting point	1315°C
Specific heat capacity	840 J/kg
Specific gravity	2.6
Thermal conductivity	0.062 to 0.065 W/m°C

Vermiculite is used widely as an aggregate in insulating concretes where thermal insulation and density are important. Thus, it is used in roof decks, floor slabs and prefabricated panels. Vermiculite is also used in fireproofing structural steel, in both panel form and by direct spraying onto the structural member. Vermiculite plasters are less than 50% of the density of conventional sand plasters, have good thermal insulation and sound absorption properties, and give protection against moisture condensation. All these are important factors when lightweight plasters are used in walls and ceilings. Vermiculite is also used extensively as loose insulation in walls and ceilings, and as fill in hollow concrete masonry and cavity walls. Vermiculite mixed with various binders, such as normal Portland, high alumina or silica cements, is used to insulate steam pipes, boilers and furnaces.

Loose vermiculite is used at elevated temperatures to regulate or slow the cooling of molten metals and metal ingots to prevent cracking. It is also used on the surface of molten metal in ladles to entrap liquid slag to facilitate its removal.

Exfoliated vermiculite mixed with soil is used extensively on lawns and in gardens. It is used on new or rebuilt lawns as a soil conditioner or, for established lawns, as a top dressing. In addition to breaking up heavy clay soils, it is an excellent fertilizer and herbicide carrier. The high absorbency makes vermiculite useful in carrying nutrients such as liquid fats in animal feed. Vermiculite is mixed with peat and plant nutrients in soilless hydroponic plant propagation. More detailed information on various agricultural and horticultural uses can be found elsewhere (35).

Minor applications include usage as an oil absorbent, in high-temperature grease, as poultry litter, in packaging, and in metallurgical mould linings.

The various uses of vermiculite require different sizes and densities; Tables 7 and 8 show typical ranges for raw concentrated and exfoliated vermiculite.

Grades 1 and 2 are used in loose insulation, concrete aggregate and horticultural applications; grades 3 and 4 are used for plaster and fireproofing; grade 5 is used as filler.

Table 7. Size and density of raw vermiculite (36)

Grade	Size range, μm	Density range, kg/m^3
1	6 680 - 1 700	800 - 1 040
2	2 360 - 1 180	800 - 1 040
3	1 700 - 425	800 - 1 040
4	600 - 212	720 - 1 040
5	-425	640 - 800

Table 8. Grading and density of exfoliated vermiculite (37)

Grade	1	2	3	4	5
Sieve size	Cumulative % retained				
9.5 mm	0 - 10				
4.75 mm	30 - 60	0 - 5			
2.36 mm	65 - 95	20 - 80	0 - 10		
1.18 mm	85 - 100	75 - 99	20 - 60	0 - 5	
600 μm		90 - 100	65 - 95	15 - 65	0 - 10
300 μm			75 - 98	60 - 98	10 - 50
150 μm			90 - 100	90 - 100	55 - 85
Density kg/m^3	64 - 112	64 - 128	80 - 144	96 - 160	128 - 176

Vermiculite Industry in Canada

The only Canadian activity in the industry, except for the two noted short periods when vermiculite was mined in Ontario, is the exfoliation of imported raw material, which began in 1931 in St. Boniface, Manitoba. In 1988, vermiculite was exfoliated at six locations by three companies as follows:

- Annapolis Valley Peat Moss Co., Berwick, N.S.;
- W.R. Grace & Co. of Canada Ltd., Ajax and St. Thomas, Ont.,
Winnipeg, Man., and Edmonton, Alta.
- Domtar Inc., Montréal, Que.

Imports of vermiculite in Canada during 1988 are reported in Table 9.

Table 9. Canadian imports of vermiculite (38)

	1988	
	(tonnes)	(\$000)
Vermiculite, unexpanded		
United States	14 510	2 591
South Africa	7 115	1 021
Total	21 625	3 612
Exfoliated (expanded) vermiculite		
United States	271	304

Source: Statistics Canada

Prices

The price of vermiculite is based largely on South African production and varies from U.S. \$190 to \$330 per tonne. Crude U.S. bulk vermiculite is less expensive, selling for U.S. \$120 to \$250 per tonne.

CANMET STUDIES

Background

Twenty-three CANMET mica beneficiation studies (39-61) and three mica studies conducted by other organizations (62-64) were reviewed. Sixteen CANMET studies of vermiculite beneficiation (65-80) and one vermiculite study conducted by Lakefield Research (81) were also reviewed. Appendix 1 presents summaries of CANMET mica studies; Appendix 2, summaries of the three mica studies by other organizations; Appendix 3, summaries of CANMET vermiculite studies; and Appendix 4, a summary of the vermiculite study by Lakefield Research.

The summary of each study includes, where known, the original sample weight, head analyses, mineralogy, beneficiation methods, beneficiation product sizes, concentrate grades and recoveries, and remarks or observations of particular interest. The original sample weight is indicative of the scale of investigation, whether bench, laboratory, semi-pilot plant or pilot plant. The head analyses provide data concerning the mineral content and whether the sample originates from a high- or low-grade deposit. Mineralogical information not only identifies major and minor minerals, but also provides data regarding association between minerals and host rocks. The liberation size in many cases is either not known or not stated; the beneficiation product size is quoted since, by inference, product size under optimum test conditions usually equates to liberation size. Beneficiation methods are

important as a guide for future studies of ores with similar mineral assemblages, and concentrate grade and recovery figures provide an indication of how efficient the beneficiation methods were in achieving a specification product. Additional data regarding flotation parameter and reagent concentration are also reported. Where possible, studies common to a particular deposit are grouped together for continuity and convenience of reference.

The noted studies of mica and vermiculite were conducted by CANMET and its predecessor, Mines Branch, between 1929 and 1988. The majority of mica studies were made on samples from Quebec, Ontario and British Columbia; most vermiculite studies, with one exception, were made on samples from Ontario.

Scale

The feed weight of samples for most mica studies was less than 225 kg; three studies (42, 58, 62) were conducted on ore samples weighing 500 kg or more. Similarly, the feed weight of samples for most vermiculite studies was less than 225 kg; three studies (76, 77, 79) were conducted on ore samples weighing 315 kg or more.

Head Analyses

The analyses of mica samples varied widely, from 7% muscovite in a copper tailings ore from Ashcroft, B.C., (61) to 90% muscovite in a muscovite-biotite schist from Portneuf, Quebec (46). The range of analyses for most ores was between 20 and 50% muscovite or phlogopite mica.

The content of vermiculite in samples also varied widely, from 8% in a sample from North Templeton, Quebec, (65) to 99% in a micaceous vermiculite ore from Cargill, Ontario (78). The range of analyses for most ores was between 12 and 35% vermiculite.

Mica

Analysis

A standard method for the analysis of mica has not yet been developed. Chemical analysis is not suitable because micas are essentially aluminum and potassium silicates, with either magnesium or iron; some varieties contain sodium, lithium or titanium.

The methods generally employed include hand sorting for large flakes, air tabling, magnetic separation, heavy liquid analysis and brightness determinations.

Hand sorting is practical only for liberated flakes coarser than 1.7 mm. Intermediate sizes below 1.7 mm and coarser than 300 μm , if liberated and sized within narrow limits, can in some cases be

analyzed by air tabling. The successful separation of mica by air classification is limited by the shape of the accompanying waste minerals.

The Franz isodynamic magnetic separator can separate strongly magnetic minerals and, to some extent, para-magnetic minerals. The Franz separator has been used successfully on a number of micaceous ores as an analysis technique.

Heavy liquid separation of mica from other minerals using a density gradient is quite reliable, although time consuming. The principle upon which separation depends is a density gradient using various heavy liquids at different specific gravities in a single container with a mechanism for removing specific density fractions.

Brightness determinations are a useful guide for assessing the degree of beneficiation of concentrated mica products.

Mineralogy

The two most common varieties of mica are muscovite and phlogopite. The muscovite in the various samples was either in granite pegmatites or in schists. When occurring in granite pegmatites, typically associated minerals were quartz, feldspar and base-metal sulphide minerals. When present as a mica schist, accessory minerals included biotite, tourmaline, chlorite, magnetite, garnet, iron oxides, graphite, calcite, serpentine, tremolite, apatite and base-metal sulphide minerals. Phlogopite occurred with quartz, calcite, serpentine and base-metal sulphides.

Processing

The size of muscovite in most of the muscovite mica samples was equivalent to that of flake mica. Processing involved successive crushing and sizing to recover a range of variously sized products. The maximum product size was 25 mm (40, 48) and the minimum, 210 μm (39). The importance of careful crushing and sizing was illustrated in one study where nine products were separated between 2.4 mm and 210 μm (49). Sizing was by screening for the coarser sizes and by air classification for the finer. The choice of crushing technique to best preserve maximum flake size, while producing the minimum amount of fines, was investigated in one study (59). A comparison of crushing by jaw, rolls, impact and cone crushers indicated that jaw crushing produced the best results for reduction ratio and minimum production of 210 μm fines.

When the content of muscovite was too low for recovery by sizing alone, several methods of beneficiation were employed. These included wet and dry air tabling, Humphrey's Spiral, and electrostatic separation. The criterion for separation was not specific gravity, but rather utilization of the unique shape of muscovite. The most successful techniques were wet tabling at minus 700 plus 250 μm (56) and dry tabling at minus 2.4 mm plus 600 μm (53); successful separation depended on prior desliming. A bowl classification study successfully separated phlogopite at 75 μm (41).

The problem of desliming was evident in three studies where flotation was employed (54-56). Flotation was successful using the acid-alkaline system (54) and the alkaline system (55). Details of flotation parameter data are reported in Table 10.

Table 10. Muscovite flotation parameter data

Method	pH	Reagent concentration kg/t	
Acid	2.5	NaOH	1.0
		Armac T	0.23
		Pine oil	0.05
Alkaline	9.8	NaOH	1.0
		Na ₂ CO ₃	1.0
		Na ₂ SiO ₃	0.5
		Armac T	0.13
		Oleic acid	0.50

Magnetic separation was employed to remove biotite (48) and other iron oxide minerals. One study utilized different levels of magnetic intensity to separate graphite, but no details were given (57).

Phlogopite beneficiation techniques were basically the same as for the beneficiation of muscovite. However, the size range over which phlogopite was recovered was wider, from 15 mm to 75 μ m.

Grades and recoveries for muscovite and phlogopite studies were not consistently reported. In studies where grades and recoveries were reported, high grades were achieved only at the expense of recovery. Thus, a phlogopite concentrate analyzed 95% phlogopite with a recovery of 60% (53), and a muscovite concentrate analyzed 91% muscovite with a recovery of 60% (57). The maximum reported recovery for muscovite from all tests was 95% (51).

Flotation

Muscovite was successfully concentrated from a sample of mica schist ore from Kaladar, Ontario, by the acid and alkaline methods (54). The alkaline method produced higher grades of muscovite than the acid method. The recoveries were similar for each method. A typical concentrate obtained by the acid method analyzed about 70% muscovite with a recovery of 65%, and a typical concentrate by the alkaline method analyzed 80% muscovite with a recovery of 68%. An estimated 20% of recoverable muscovite was lost by each method as minus 150 μ m slimes.

A later study, using the alkaline method to float muscovite from a deslimed fraction of minus 840 plus 75 μ m mica schist, produced a concentrate analyzing 90% muscovite with a recovery of 60% (55).

Mica - Heat Resistance

Two samples of mica were evaluated for heat resistance properties. The first, a sample of black mica, was not considered suitable because scaling and exfoliation were evident when heated to 900 and 1000°C (44). The second, a sample of phlogopite, was heated in increments of 55°C from 816 to 1204°C. There was no visible change until 1093°C, when incipient clouding and bloating occurred. At 1204°C, the phlogopite was cloudy to silvery in appearance, not significantly bloated, still slightly elastic and structurally strong (47).

Vermiculite

Analysis

The chemical composition of vermiculite, a hydrous magnesium silicate with some replacement of silicon by aluminum, indicates a composition less subject to variation than the micas. Chemical analyses of SiO_2 , MgO and Al_2O_3 can to some extent, therefore, indicate vermiculite content. Vermiculite, when present in multi-mineral assemblages, is usually analyzed by X-ray diffraction.

Vermiculite exhibits shape characteristics similar to those of mica, so that physical methods of analysis can be employed. Thus, coarse vermiculite greater than 2 mm in size is analyzed by hand sorting. Intermediate size fractions below 1.7 mm and coarser than 300 μm are analyzed by air tabling or particle counting under the binocular microscope.

Mineralogy

Vermiculite, typical of its association with basic rocks, occurred with quartz, hornblende, feldspar, talc, diopside, calcite and clay minerals.

Processing

The shape of vermiculite, being similar to that of mica, enabled air separation techniques to be used to beneficiate this mineral. The unique ability to expand on heating (exfoliate) was a distinct advantage in the processing of vermiculite. The basic processing route was successive crushing and sizing to recover a range of variously sized products. The maximum product size was 9.5 mm (76) and the minimum, 150 μm (74). Following preliminary size separation, products were exfoliated, and the siliceous gangue material was separated from the expanded vermiculite by winnowing (air classification). Exfoliation in some studies also reduced the bulk density, which is important in insulation and concrete applications. One study improved the bulk density and yield after exposure to rainwater weathering (67).

Alternate methods of beneficiation included air jigging and air tabling, wet tabling, Humphrey's Spiral, electrostatic separation, agglomerate (skin) flotation, froth flotation, autogenous grinding and heavy-media separation.

Air jigging and tabling were employed at sizes between 9 mm and 150 μm (79), and wet tabling was used at sizes between 2.4 mm and 300 μm (76, 77). An adaptation of wet tabling, agglomerate skin flotation, was assessed at sizes between 2.4 mm and 300 μm . Agglomerate flotation, like froth flotation, was successful only on easily delaminated vermiculite. Brittle vermiculite, which slimed easily, was inimical to each technique (76).

Electrostatic separation was successful in separating vermiculite, a nonconductor, from siliceous gangue in two studies (70, 76). Magnetic separation was not used as a primary method of separation but rather to separate minerals like diopside (75). However, diopside removal in this study was more successfully accomplished by heavy liquid separation, when the vermiculite and talc reported in the float fraction.

Grades and recoveries were not consistently reported in the earlier studies. Yield, reported as cubic metres/tonne, is a measure of recovery, and a value of 1.0 m^3/t was considered high.

Ontario vermiculite samples from Sudbury, Stanleyville, and Cargill township areas were frequently evaluated. The maximum recovery of vermiculite from Stanleyville ore was about 75% (80); a grade of 75% vermiculite at a recovery of 66% was also reported (77). Vermiculite from the Sudbury area was more easily concentrated, and a recovery of 94% was obtained in one study (74). Recently, two studies (78, 79) were conducted to evaluate the vermiculite-phosphate deposits from the Cargill Township area. A larger trench sample resulted in a range of grades: 93% for plus 12 mm, 58% for minus 12 plus 1.5 mm, and 76% for minus 1.5 mm plus 150 μm (79).

Flotation

Vermiculite flotation was attempted in two studies (76, 77), but the generation of slime material reduced selectivity in both. The best results were obtained with ore from Stanleyville (77), when a tertiary amine (Ethomeen T/15) at pH 10.0 produced a concentrate analyzing about 60% vermiculite; no details of reagent concentration data were reported.

CONCLUDING COMMENT

This report is the fifth in a series of summary reports on industrial minerals. These reports are designed to assist individuals and companies having interest in industrial minerals in Canada.

A wide distribution of the summary report series is planned as a means of encouraging interest in the further development of industrial minerals for use in many diverse applications, such as fillers for everyday products like paint and rubber and, in the high-technology sector, for products like high-performance plastics, silicon chips and fibre-optic filaments.

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APPENDIX A

SUMMARIES OF CANMET MICA STUDIES

NOVA SCOTIA

Identification : N.S. - 1 (Ref. No. 39)*

Report - Title : MICA FROM EAST GUYSBOROUGH CO.
- Author : C.G. Bruce
- No. and Date: *Industrial Minerals Report* No. 203, 1953.

Sample Description : 10 kg of white muscovite in 20 mm books with quartz and feldspar as the principal impurities.

Objective : To concentrate and recover muscovite.

Processing : Crushing to 12 mm and sizing at 4.8 mm, 2.4 mm, 1.2 mm and 210 μ m.

Results : About 60% of the mica was recovered at 1.2 mm. The recovered mica was strong, pliable and easily delaminated. Recovery could be increased to more than 80% by air table treatment of middling products.

Potential Use : Too low grade for most uses, but possibly could be used as a filler in some applications.

* CANMET identification with reference number in brackets.

Identification : N.S. - 3 (Ref. No. 40)

Report - Title : BENEFICIATION OF MICA FROM MICA HILL
- Author : R.K. Collings
- No. and Date: Unpublished results, 1987.

Sample Description : Two samples of high-grade pegmatitic mica.

Objective : To produce a high-grade muscovite product.

Processing : Stage crushing by rolls and hammer mill with sizing at plus 25 mm, minus 25 plus 12.5 mm, minus 12.5 plus 6.7 mm, and minus 6.7 mm.

Results : The plus 6.7 mm fraction contained exfoliated sheets and unexfoliated slivers of mica. The minus 6.7 mm fraction consisted mainly of fine exfoliated flakes of mica.

Potential Use : Probably suitable for filler applications.

QUEBEC

- Identification : Que. ~ 1 (Ref. No. 41)
- Report - Title : GRINDING OF SCRAP MICA FROM ST. PIERRE DE WAKEFIELD
- Author : R.K. Carnochan
- No. and Date: *Ore Dressing Investigation Report* (unnumbered), 1929.
- Sample Description : 150 kg of phlogopite scrap mica ranging in size from small flakes to pieces measuring 15 x 25 cm and up to 5 cm thick.
- Objective : To investigate grinding and sizing of scrap mica to determine optimum method for size reduction.
- Processing : Various crushing and grinding techniques in conjunction with screening were studied. These included:
- gyratory crusher, hammer mill and 'Kek' grinder;
 - wet grinding in a pebble mill followed by sizing in a Dorr bowl classifier; and
 - dry sizing using a 'Keedy' sizer, Hummer vibrating screen and rotary screens.
- Results : Comminution was best achieved using a hammer mill to minus 12 mm plus 210 μ m, and a smaller hammer mill or 'Kek' grinder for reduction to minus 4.8 mm plus 75 μ m. Rotary screens were better than vibratory screens for sizing. The bowl classifier (wet) produced a good separation at 75 μ m, but the Gayco air separator could not separate at less than 1.7 mm. No grades or recoveries were reported.
- Potential Use : Unsuitable for paint because of the amber colour.

- Identification : Que. - 2 (Ref. No. 42)
- Report - Title : GRINDING OF SCRAP MICA FROM BLACKBURN MINE
- Author : R.K. Carnochan
- No. and Date: *Ore Dressing Investigation Report* (unnumbered), 1930.
- Sample Description : Two 500 kg samples of phlogopite scrap mica ranging in size from small flakes to pieces measuring 7 x 5 cm, and up to 1 cm thick.
- Objective : To investigate grinding and sizing of scrap mica to determine optimum method for size reduction.
- Processing : Several crushing and grinding techniques in conjunction with screening were studied. These included:
 - Sturtevant hammer mill with a Hummer vibration screen at 840 μ m;
 - 'Kek' grinding mill with a Hummer screen at 840 μ m;
 - Raymond pulverizer with a Hummer screen at 840 μ m;
 - Pre-reduction in Sturtevant hammer mill followed by 'Kek' and Raymond mills; and
 - Rotex screening of end products.
- Results : The Sturtevant hammer mill and Raymond pulverizer were both satisfactory for grinding mica. The former had the larger capacity; the latter produced the finer product. The Rotex screen was satisfactory for screening the crushed and ground products. No grades or recoveries were reported.
- Potential Use : Unsuitable for paint because of amber colour. .

Identification : Que. - 3 (Ref. No. 43)

Report - Title : TREATMENT OF MICA FROM WILSON'S CORNERS
- Author : R.K. Carnochan
- No. and Date: *Ore Dressing Investigation Report* (unnumbered), 1933.

Sample Description : 50 kg of mica from the mine dump; size of mica ranged from 1 to 2 cm down to fine flakes; much of the mica was free, but a small percentage was bound to rock particles.

Objective : To investigate the recovery of mica from mine dump material.

Processing : Stage rolls crushing to 10 mm with separation of a plus 10 mm product; further reduction of the minus 10 mm product to 4.8 mm and separation of the minus 10 plus 4.8 mm fraction. The crushing and screening sequence was repeated at 2.4 and 1.7 mm. The minus 1.7 mm fraction, which contained some flake mica, was wet tabled.

Results : Results showed that each successive stage of crushing and screening yielded lower grades and smaller quantities of mica. Tabling of the minus 1.7 mm mica resulted in the further recovery of only small additional quantities of mica. No grades or recoveries were reported.

Potential Use : Not determined.

Identification : Que. - 4 (Ref. No. 44)

Report - Title : REPORT ON A SAMPLE OF MICA FOR HEAT RESISTANCE TESTS
FROM PONTIAC CNTY.

- Author : C.H. Freeman

- No. and Date: *Ore Dressing Investigation Report* (unnumbered), 1938.

Sample Description : A sample of black mica.

Objective : To determine suitability for heat resistance purposes.

Processing : Heat treatment at 900 and 1000°C.

Results : The appearance changed from black to brownish black with part of the
edge turning a silvery white. The surface also had the appearance of
scaling; some exfoliation was evident.

Potential Use : Not suitable for heat resistance purposes.

Identification : Que. - 5 (Ref. No. 45)

Report - Title : THE RECOVERY OF MICA FROM A MOLYBDENITE TAILING
OBTAINED FROM LA CORNE TWP., ABITIBI

- Author : R.K. Carnochan

- No. and Date: *Ore Dressing Investigation Report* (unpublished), 1939.

Sample Description : A 12 kg sample of molybdenite tailings containing muscovite, and a 7 kg feed sample containing molybdenite and muscovite.

Objective : To separate muscovite at a coarse size.

Processing : The tailings sample was screened at 210 μm , and the plus 210 μm fraction was tabled. The minus 210 μm fraction was subjected to flotation.

The feed sample was crushed to pass 820 μm , and screened at 300 and 150 μm . Each size fraction was tabled separately, and the mica products were subjected to flotation to remove molybdenite.

Results : Good results were obtained only on the feed sample where plus 820 μm , minus 820 plus 300 μm , and minus 300 plus 150 μm fractions produced clean muscovite. The recovery was not, however, very high.

Potential Use : Possibly suitable for filler applications.

- Identification : Que. - 6 (Ref. No. 46)
- Report - Title : PROCESSING OF MICA CONCENTRATES FROM PORTNEUF CO.
- Author : C.G. Bruce
- No. and Date : *Industrial Minerals Report* No. 166, 1953.
- Sample Description : 75 kg of concentrate from Montauban Les Mines containing about 90% mica.
- Mineralogy : Principally muscovite with minor biotite. Accessory minerals included magnetite, sphalerite, pyrrhotite, graphite, calcite, quartz and tremolite. Mica liberation at 600 μm .
- Objective : Recovery of muscovite mica by dry processing methods.
- Processing : Sizing to minus 600 plus 210 μm . Magnetic separation, electrostatic separation and flotation to concentrate mica. Separate delamination processing studies were conducted by a hammer mill, Victoria pin mill and an air jet mill in an attempt to reduce bulk density.
- Results : Little success was achieved in the recovery of muscovite by electrostatic separation, magnetic separation or flotation. Reduction of bulk density was greatest using the air jet mill (672 to 832 kg/m^3) but not to a satisfactory value. Further magnetic separation trials, followed by differential fine grinding, were recommended.
- Potential Use : The finer sizes may have possible filler use for certain applications.

Identification : Que. - 7 (Ref. No. 47)

Report - Title : REPORT OF HEAT TEST
- Author : C.G. Bruce
- No. and Date: *Industrial Minerals Report* No. 333, 1955.

Sample Description : Eight specimens of phlogopite.

Objective : Testing for heat resistance.

Processing : Each specimen was heated in a furnace: the first to 810°C, the second to 871°C, and each remaining specimen by increasing increments of 55°C.

Results : There was no visible change until 1093°C, when incipient clouding and bloating occurred. At 1204°C, the phlogopite was cloudy to silvery in appearance, not seriously bloated, still slightly elastic and structurally strong.

Potential Use : Suitable for heat resistance applications.

Identification : Que. - 8 (Ref. No. 48)

Report - Title : PRELIMINARY REPORT ON THE MICA SAMPLE FOR
STRATMAT LTD., QUEBEC

- Author : J.E. Reeves

- No. and Date: *Industrial Minerals Report* No. 454, 1957.

Sample Description : A sample of mica-bearing rock in 10 bags containing major feldspar, quartz and muscovite with minor biotite, apatite and tourmaline. Muscovite sheets up to 100 mm in size were observed, but strains and fractures precluded the possibility of deriving sheet mica.

Objective : To produce a high-grade muscovite product free of biotite.

Processing : Stage crushing by jaw and rolls crusher with screening to recover coarse size fractions of a muscovite sample low in biotite, and a sample high in biotite.

The sample high in biotite was further processed by crushing to minus 1.2 mm followed by dry, high-intensity magnetic separation to recover biotite.

Results : Stage crushing and sizing of the sample low in biotite produced a high-grade 98% muscovite in all the size fractions from 25 mm down to 600 μ m. Magnetic separation of the sample high in biotite was only partially successful in removing biotite to obtain a 75% muscovite product.

Potential Use : Possibly suitable as scrap mica.

ONTARIO

- Identification : Ont. - 1 (Ref. No. 49)
- Report - Title : WASTE DUMP MATERIAL FROM PURDY MICA MINE,
EAU CLAIRE
- Author : C.G. Bruce
- No. and Date: *Industrial Minerals Report* No. 148, 1952.
- Sample Description : 225 kg of mica tailings containing about 15% muscovite with minor biotite.
- Objective : To recover muscovite by dry processing methods.
- Processing : Removal of coarse waste rock, successive crushing and screening down to 4.8 mm with removal of a mica product as the screen oversize. Further reduction of the minus 4.8 mm product, and sizing by air classification to produce various successively finer mica products down to 210 μ m. Hammer mill reduction of the undersize followed by air classification.
- Results : Overall recovery of mica was estimated at 84%; biotite appeared to be concentrated in the minus 1.7 mm fraction, from which it could be separated by magnetic separation. Recovery of scrap and small-sheet mica thus appears feasible.
- Potential Use : Suitable as grinding scrap and small-sheet mica.

Identification : Ont. - 2 (Ref. No. 50)

Report - Title : PHLOGOPITE WASTES, HINCHINBROOK TWP.
- Author : C.G. Bruce
- No. and Date : *Industrial Minerals Report* No. 182, 1953.

Sample Description : 85 kg of waste material from a mining operation in Hinchinbrook Township containing an estimated 40% phlogopite.

Objective : To recover phlogopite from waste.

Processing : Screening at 13 mm followed by various combinations of jaw, rolls and hammer mill reduction of the plus 13 mm oversize, with sizing to produce a minus 13 plus 9.5 mm mica product, a minus 9.5 plus 3.4 mm mica product, and a minus 3.4 plus 1.7 mm mica product.

Results : Approximately 50% of the mica present in the original sample was recovered in the coarser screen fractions. It was estimated that 75 to 80% of the mica remaining in the fine, minus 1.7 mm tailings could be recovered by air tabling or air classification.

Potential Use : Not determined.

Identification : Ont. - 3 (Ref. No. 51)

Report - Title : MICA SCHIST FROM STURGEON FALLS
- Author : C.G. Bruce
- No. and Date: *Industrial Minerals Report* No. 197, 1953.

Sample Description : 18 kg of mica schist from Caldwell Township containing muscovite flakes up to 6.4 mm in size associated with quartz and minor impurities including serpentine, magnetite, graphite and sulphides. Mineral content was estimated at 20% mica, 75% quartz and 5% ferromagnesian minerals.

Objective : To recover muscovite.

Processing : Crushing by jaw crusher and hammer mill to 2.4 mm; horizontal draft air classification followed by screening at 210 μ m to recover a mica concentrate. Rejects were recrushed through the hammer mill to 1.6 mm and reclassified to produce a second mica product.

Results : Recovery of mica was approximately 45%. The mica was unusually friable but resistant to delamination; thus losses to tailings were high. Air tabling could be used as an adjunct to the horizontal air classifier to improve overall recovery.

Potential Use : Not determined.

Identification : Ont. - 4 (Ref. No. 52)

Report - Title : MICA PEGMATITE FROM PARRY SOUND

- Author : C.G. Bruce

- No. and Date: *Industrial Minerals Report No. 228, 1954.*

Sample Description : 225 kg of mica pegmatite containing 25% muscovite with feldspar, quartz and minor sulphides.

Objective : To recover mica by dry processing methods.

Processing : Reduction by jaw crusher to 13 mm, and by hammer mill to 2.4 mm; minus 210 μ m removed and plus 210 μ m treated in a horizontal air classifier to produce a minus 2.4 mm plus 210 μ m mica product. Classifier rejects were reground in the hammer mill to 1.6 mm and repassed through the air classifier to yield a minus 1.6 mm plus 210 μ m mica product. The final classifier rejects were screened at 840 μ m to recover additional minus 840 plus 210 μ m mica.

Results : Estimated recovery of mica was 58% with 36% of the mica being recovered by air classification following primary hammer mill crushing using 3 mm grates. An additional 22% was obtained by air classification following hammer mill reduction using 1.5 mm grates.

Potential Use : Good quality grinding scrap.

- Identification : Ont. - 5 (Ref. No. 53)
- Report - Title : PHLOGOPITE WASTE DUMP MATERIAL FROM FRONTENAC CO.
- Author : C.G. Bruce
- No. and Date: *Industrial Minerals Report No. 233, 1954.*
- Sample Description : 55 kg of waste dump material containing an estimated 23% phlogopite from Thirty Island Lake Mine, Bedford Township. Impurities include quartz, calcite, serpentine and minor metallics.
- Objective : To concentrate and recover phlogopite.
- Processing : Two processes for the recovery of mica were investigated:
(a) size reduction by stage rolls crushing and screening at 15, 8 and 4.8 mm. Screening of the minus 4.8 mm undersize at 2.4 mm, 1.2 mm, 840 μ m and 600 μ m to yield products retained at each size fraction. Further treatment of each fraction by air tabling;
(b) reduction by a rolls crusher and screening to produce a mica concentrate; reduction of the undersize by the hammer mill set at 6.7 mm with air classification and screening to yield a mica product. The undersize was recrushed, repassed through the air classifier and screened at 1.7 mm.
- Results : (a) A concentrate grading about 95% mica was obtained at a recovery of 40%.
(b) A concentrate grading 95% mica was obtained at a recovery of 60%.
- Potential Use : Not determined.

- Identification : Ont. - 6 (Ref. No. 54)
- Report - Title : KALADAR MICA PROJECT
- Authors : M. Lavallée, J.M. Lamothe and D.G. Feasby
- No. and Date: *Division Report 87-3(CR), 1987.*
- Sample Description : Two samples, 170 kg and 100 kg, of drill core from Kaladar, Ontario, containing 20 to 25% muscovite mica. Muscovite was finely divided; quartz was the principal impurity with lesser quantities of biotite, chlorite, feldspar, garnet and iron minerals. Liberation was determined at 420 μm .
- Objective : To produce a muscovite concentrate by dry and wet processing methods.
- Processing : Preliminary tests were conducted on the 100 kg sample to establish optimum process parameters. The core samples were reduced to 1.7 mm by jaw and gyratory crushers, and to 420 μm by impact mill. Dry processing included air tabling and magnetic separation. Wet processing involved grinding to 420 μm , scrubbing with NaOH, and desliming at 100 μm followed by flotation and magnetic separation. Flotation was conducted using the acid and alkaline systems.
- Results : Dry processing recovered 40% of the muscovite in a concentrate containing 75% mica. Wet processing recovered about 60% of the mica; however, recoveries up to 65% in a concentrate averaging 90% muscovite were considered to be possible. Processing resulted in the generation and substantial loss of fines, particularly in the wet system.
- Potential Use : Possible use for some filler applications.

Identification : Ont. - 7 (Ref. No. 55)

Report - Title : BENEFICIATION OF MICA SCHIST FROM LAVANT TWP.
- Author : D.G. Feasby
- No. and Date: Unpublished results, 1988.

Sample Description : A 230 kg sample of a weathered mica schist containing about 25% muscovite with minor amounts of iron oxides and ferro-magnesian minerals.

Objective : To produce a high-grade muscovite product.

Processing : Stage crushing by a combination of jaw, rolls and cone crushing to minus 2.4 mm. Further beneficiation included air tabling and flotation, using the alkaline method, on minus 840 plus 75 μ m scrubbed and deslimed material.

Results : A muscovite concentrate analyzing 90% with a 60% recovery was obtained.

Remarks : The muscovite exhibited a good crystal habit, high aspect ratio and no evidence of kink-banding.

Potential Use : Possibly suitable for filler applications.

BRITISH COLUMBIA

- Identification : B.C. - 1 (Ref. No. 56)
- Report - Title : CONCENTRATION OF MICA FROM PRINCE RUPERT
- Author : R.K. Carnochan
- No. and Date: *Ore Dressing Investigation Report 606, 1935.*
- Sample Description : 150 kg of mica schist from Baker Inlet about 40 km south of Prince Rupert; sample consisted of fine flakes of altered muscovite associated with magnetite and minor quartz; magnetite was embedded in the mica flakes.
- Objective : Concentration and recovery of mica.
- Processing : Various crushers and grinders were investigated including a rolls crusher, Raymond and Braun pulverizers, and a pebble mill. Separation of the mica was investigated by screening, wet tabling, air separation, flotation and magnetic separation.
- Results : The best results were obtained by crushing to 700 μm and wet tabling the minus 700 plus 250 μm and minus 250 μm fractions; recovery of mica concentrates was 45 and 20%, respectively. Air separation in a Gayco classifier was improved by first stage grinding in the Raymond pulverizer to 300 μm ; good results were obtained with minus 300 plus 150 μm , minus 150 plus 75 μm , and minus 75 μm fractions; recoveries were 23, 39 and 17%, respectively. Magnetic separation proved to be effective only with the coarser, plus 600 μm sizes. Flotation results were poor.
- Potential Use : Not determined.

Identification : B.C. - 2 (Ref. No. 57)

Report - Title : MICA SCHIST FROM ALBREDA, VALEMOUNT
- Author : C.G. Bruce
- No. and Date: *Industrial Minerals Report No. 202, 1953.*

Sample Description : 100 kg of mica schist with associated quartz, garnet and disseminated graphite. The mica was predominantly muscovite (about 50% of the sample) and was finely disseminated.

Objective : To recover and refine mica.

Processing : Stage reduction by a hammer mill set at 1.7 mm, followed by treatment in a horizontal draft air classifier and screening at 210 μ m to recover a coarse mica concentrate. High-intensity magnetic separation was then used to remove graphite, and low-intensity separation, to concentrate a white muscovite product. This product was then ground to 75 μ m and checked for reflectivity.

Results : Reduction by hammer mill and concentration by air classification produced a concentrate analyzing >91% mica (98% grade in the plus 210 μ m fraction, and 88% grade in the minus 210 μ m fraction) for a recovery of 60% of the total mica. Magnetic separation and grinding of the nonmagnetic fraction resulted in a product having a reflectivity of 64% (based on a $MgCO_3$ standard).

Potential Use : Reflectivity is too low for paint applications, but product may be suitable for some filler uses.

- Identification : B.C. - 3 (Ref. No. 58)
- Report - Title : CONCENTRATION OF MICA FROM VALEMOUNT
- Author : F.H. Hartman
- No. and Date: *Investigation Report* 62-38, 1962.
- Sample Description : 500 kg of mica schist containing muscovite and biotite, minus 2.5 mm in size; associated gangue minerals included quartz and garnet.
- Objective : To develop an improved flow sheet for the processing and recovery of mica.
- Processing : Four types of crushing systems to prepare rod mill feed were compared: jaw, rolls, cone and hammer mills. The minus 20 mm jaw crusher product was ground in a rod mill, and the products from the rod mill were combined and screened. The minus 2.5 mm plus 420 μ m and minus 420 plus 150 μ m high mica fractions were concentrated by Humphrey's Spiral, wet table and Jones magnetic separator.
- Results : Jaw crushing gave the best overall performance for the production of plus 175 μ m mica. Grinding in the rod mill to at least minus 2.5 mm was required to delaminate and free the mica. The Humphrey's Spiral was ineffective, but the wet table produced good results; recovery of mica was about 55 to 68% in most tests. Jones magnetic separation tests produced a clear high-grade nonmagnetic mica.
- Potential Use : Possible paint application, but no brightness tests were conducted to confirm this.

Identification : B.C. - 4 (Ref. No. 39)

Report - Title : BENEFICIATION OF A MICA SCHIST FROM VALEMOUNT
- Author : R.A. Wyman
- No. and Date: Unpublished results, 1962.

Sample Description : A sample of mica schist.

Objective : To produce high-grade muscovite suitable for filler applications.

Processing : Comparison of crushing techniques using jaw, rolls, impact and cone crushers. The crushed product was ground in a rod mill, and the ground product was screened to produce minus 2.4 mm plus 420 μ m and minus 420 μ m, and minus 420 plus 210 μ m. Each size fraction was beneficiated by Humphrey's Spiral and wet tabling. Magnetic separation was applied to products from wet tabling.

Results : Jaw crushing gave the best results for reduction ratio and minimum production of minus 210 μ m fines. Wet tabling was more successful than Humphrey's Spiral in concentrating mica. A high-grade concentrate was produced with each size fraction for a total weight recovery of 48.2%.

Potential Use : Suitable for filler applications.

Identification : B.C. - 8 (Ref. No. 60)

Report - Title : BENEFICIATION OF PONCHA PASS MICA
- Author : R.K. Collings
- No. and Date : Unpublished report, 1984 (START project).

Sample Description : 25 kg of minus 1.7 mm mica ore, principally muscovite and quartz with minor phlogopite and biotite. The mica content was estimated at 25 to 30%.

Objective : To concentrate the contained mica.

Processing : Air tabling (Denver and Kipp Kelly) on sized samples: plus 600 μm , minus 600 plus 300 μm , minus 300 plus 150 μm fractions.

Results : The Denver air table did not concentrate mica at any size, and the Kipp-Kelly air table concentrated mica in only the minus 300 plus 150 μm size range. A concentrate analyzing 92% with a recovery of 32% was obtained.

Potential Use : Not determined.

Identification : B.C. - 6 (Ref. No. 61)

Report - Title : BENEFICIATION OF MICA FROM VALLEY COPPER TAILINGS

- Author : R.K. Collings

- No. and Date: Unpublished report, 1984 (START project).

Sample Description : 25 kg of mica-biotite tailings from Valley Copper Mine, Ashcroft, 60 km west of Kamloops, B.C. The principal minerals were quartz and feldspar; muscovite and biotite probably represented 5 to 10% of the sample weight.

Objective : To concentrate the contained muscovite.

Processing : Denver air table tests on sized samples, plus 600 μ m, minus 600 plus 300 μ m, minus 300 plus 150 μ m, and minus 150 μ m.

Results : There was no significant concentration of mica at any of the sizes tested.

Potential Use : Not determined.

APPENDIX B

SUMMARIES OF OTHER MICA STUDIES

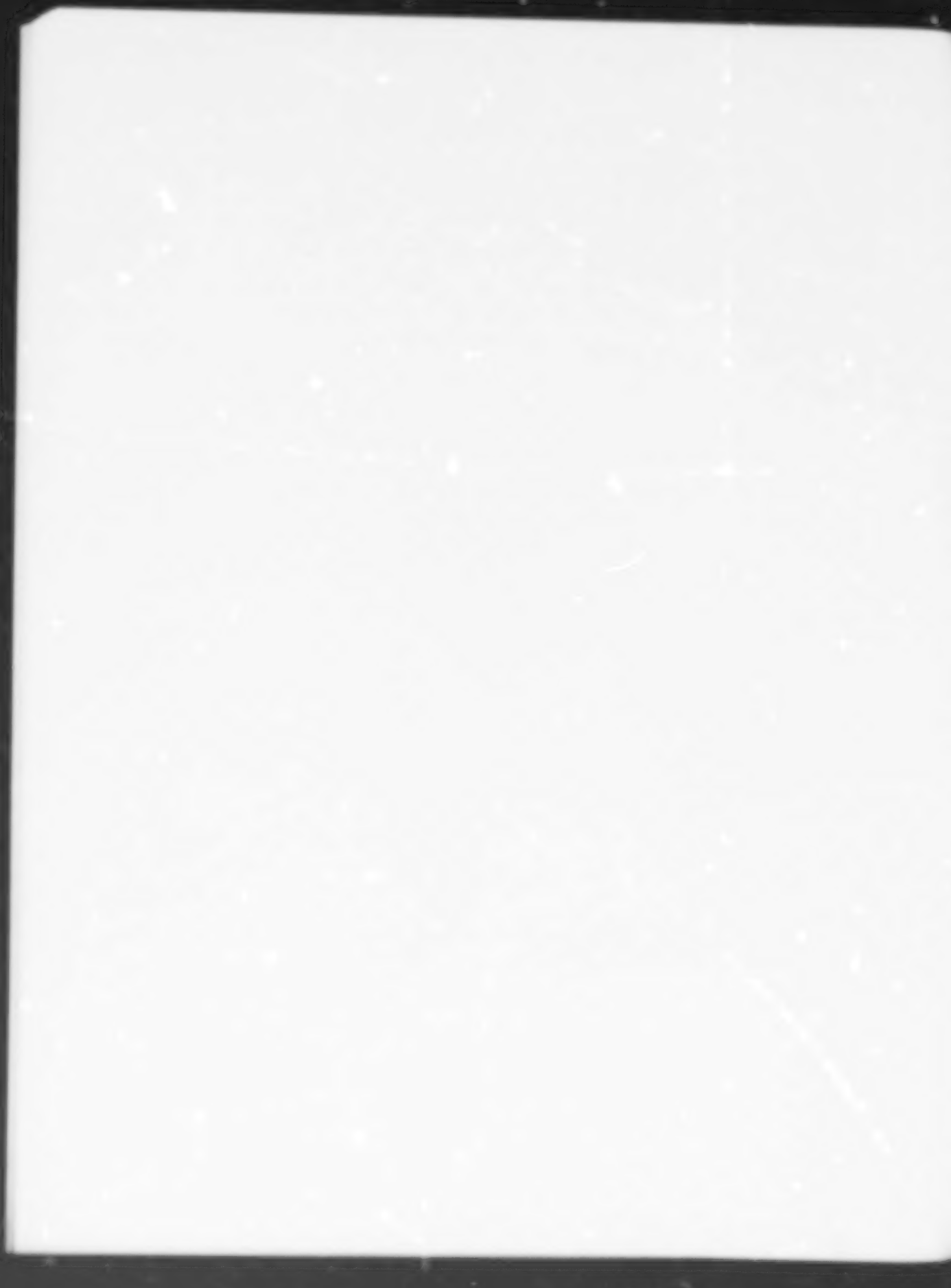
ONTARIO

- Identification : Ont. - 6 (Ref. No. 62)
- Report - Title : BENEFICIATION OF MICA FROM A SAMPLE OF TREMOLITIC FINES
- Authors : P.D.R. Mahby and J. Melnbardin
- No. and Date : ORTECH International Report 71273, 1980.
- Sample Description : A 3 t sample of tremolitic fines remaining after autogenous grinding and air classification.
- Objective : To produce separate mica and tremolite concentrates.
- Processing : Dry screening at 600 and 150 μm to produce a minus 600 plus 150 μm fraction for flotation. A mica concentrate was obtained first, followed by recovery of a tremolite concentrate from the mica tailings.
- Results : A 250 kg mica flotation concentrate was obtained using the acidic-cationic flotation method. A tremolite concentrate was obtained using a frother-collector (Aerofroth 65); no grades or recoveries were reported.
- Potential Use : Product evaluation results were not reported, but the mica may be suitable for filler applications.

BRITISH COLUMBIA

- Identification : B.C. - 7 (Ref. No. 63)
- Report - Title : MUSCOVITE SCHIST AS A SOURCE OF MICA
- Author : L. Bédard
- No. and Date : M.R.C. Project 911, 1979.
- Sample Description : Drill core samples from Valemount; muscovite deposit containing about 50% muscovite and biotite, associated with minor graphite.
- Objective : To investigate recovery of muscovite by dry processing techniques.
- Processing : Pilot-plant testwork was conducted at Quebec City which included reduction by impact mill to 1.7 mm followed by screening, air tabling, rescreening, delamination and further air tabling. High-intensity magnetic separation was employed to reject free biotite.
- Results : Recovery of muscovite was about 75%. Recovery of a smaller quantity of coarser plus 850 μm , and minus 850 plus 400 μm flake, was demonstrated.
- Potential Use : Suitable for use in drywall joint sealing compounds (98% minus 150 μm , 65% minus 45 μm).

Identification	:	B.C. - 8 (Ref. No. 84)
Report - Title	:	PROCESS STUDY OF FIVE SAMPLES OF MUSCOVITE CONTAINING ORE FROM GRENVILLE CHANNEL, PRINCE RUPERT
- Author	:	J. Kriens
- No. and Date	:	I.M.D. Report 90164-2-1, 1988.
Sample Description	:	Five samples of muscovite-containing ore associated with biotite, quartz and possibly hornblende. The mica was blocky in two samples, and small amounts of muscovite in some samples were green or amber.
Objective	:	To produce high-grade, 95% muscovite.
Processing	:	Crushing to minus 1.7 mm, wet grinding to minus 300 μ m, flotation using the alkali method, magnetic separation.
Results	:	Three of the five samples (1, 2 and 3) were concentrated to 95% muscovite. Sample 3 was considered best; muscovite was clean, colourless and appeared to have a good flake structure.
Potential Use	:	Product evaluation recommended for concentrates produced from samples 1, 2 and 3 ore.



APPENDIX C

SUMMARIES OF CANMET VERMICULITE STUDIES

QUEBEC

- Identification : Que. - 1 (Ref. No. 65)
- Report - Title : EVALUATION OF VERMICULITE FROM HULL CO.
- Author : H.S. Wilson
- No. and Date: *Mineral Processing Test Report* 60-121, 1960.
- Sample Description : Two small samples of vermiculite ore analyzing 35 and 8% vermiculite from a deposit in North Templeton Township, Hull County. The samples were minus 30 mm in size and largely composed of silver-coloured micaceous material.
- Objective : To recover and evaluate vermiculite.
- Processing : Samples were crushed to 6.4 mm, screened at minus 4.8 mm plus 840 μ m, minus 840 plus 210 μ m, and minus 210 μ m. Each fraction was treated in an electric tube furnace at a temperature between 1010 and 1040°C during a 10 to 25 sec. period. The exfoliated vermiculite was then removed by air separation and examined.
- Results : The average vermiculite content for all three size fractions of sample 1 was 30%.
- Potential/Use : Sample 1 is suitable for most commercial uses of vermiculite.

ONTARIO

- Identification : Ont. - 1 (Ref. No. 66)
- Report - Title : EXFOLIATION OF STANLEYVILLE VERMICULITE
- Author : C.G. Bruce
- No. and Date: *Industrial Minerals Report No. 212, 1953.*
- Sample Description : Five small samples of vermiculite from North Burgess Township.
- Objective : To recover and evaluate vermiculite.
- Processing : Each sample was reduced to 4.8 mm and treated by rolls crusher and ball mill to delaminate and free the vermiculite. The samples were then screened at 210 μm , and the plus 210 μm product was exfoliated in a rotary kiln.
- Results : Four of the five exfoliated samples showed bulk densities and corresponding yields as follows: 138, 166, 194 and 213 kg/m^3 and 5.2, 3.8, 3.3 and 2.4 m^3/t . Density and yield would be substantially improved by removal of unexfoliated material and rock fragments by air separation.
- Potential Use : Not determined.

Identification : Ont. - 2 (Ref. No. 67)

Report - Title : EXPOLIATION OF DIAMOND DRILL CORE FROM STANLEYVILLE
- Author : C.G. Bruce
- No. and Date: *Industrial Minerals Report* No. 261, 1954.

Sample Description : 96 m of vermiculite drill core from North Burgess Township.

Objective : To recover and evaluate vermiculite.

Processing : Representative intervals of core section were reduced to 4.8 mm by jaw crusher, to 840 μm by rolls crusher, and to about 25% minus 210 μm by rod mills. The plus 210 μm fraction was exfoliated at 925°C in a rotary kiln and the expanded vermiculite was recovered by winnowing.

Results : An average yield of 0.55 m^3/t was obtained for composite samples from the 65 to 80 m section of the diamond drill core.

: Bulk density values for subsurface samples were noticeably higher than those for surface samples. Selected core samples were processed and treated with about 2% weight of rainwater, to investigate whether surface water contributed to improved bulk density and yield. The length of treatment varied from 64 to 213 days. The samples were then exfoliated, and bulk densities and yield were determined; results indicated increased yield and lower bulk density. The yield in one test after a 64 day period was increased from 0.57 to 0.96 m^3/t , and bulk density was reduced from 293 to 206 kg/m^3 .

Potential Use : Not determined.

Identification : Ont. - 3 (Ref. No. 68)

Report - Title : INVESTIGATION OF VERMICULITE FROM NORTH BAY
- Author : C.G. Bruce
- No. and Date: *Industrial Minerals Report* No. 346, 1955.

Sample Description : Samples were obtained from a vermiculite-mica dyke in the vicinity of Lake Nipissing. Six chip samples were taken over the 30 m wide dike at intervals of about 6 m.

Objective : To recover and evaluate vermiculite.

Processing : Samples were reduced by jaw and rolls crushers, screened at 210 μm , and the plus 210 μm fraction was exfoliated in a rotary kiln. The expanded vermiculite was recovered by winnowing.

Results : Product yield was very low, averaging only 0.20 m^3/t and varying from 0.03 to 0.35 m^3/t .

Potential Use : This vermiculite is of no commercial interest.

Identification : Ont. - 4 (Ref. No. 69)

Report - Title : INVESTIGATION OF VERMICULITE FROM SUDBURY

- Author : C.G. Bruce

- No. and Date: *Industrial Minerals Report No. 353, 1955.*

Sample Description : Five small samples from the Sudbury area, 16 km southwest of Cartier Station. Three samples contained green to brown 'books' of vermiculite up to 6.4 mm in size. The fourth sample was essentially composed of minus 1.7 mm flake vermiculite, and the fifth sample consisted largely of biotite mica up to 6.4 mm in size.

Objective : To recover and evaluate vermiculite.

Processing : The two lump samples were treated by jaw and rolls crushers to free and delaminate the mica-vermiculite. The two loosely consolidated finer samples were treated by either rolls crusher or ball mill; the flake sample was not further size reduced. All products were screened at 210 μ m, and the plus 210 μ m fraction was heated by rotary kiln at 805°C to exfoliate the vermiculite, which was then recovered by winnowing.

Results : Yield from the two lump samples was very low, less than 0.31 m³/t. Yield from the remaining three samples was quite high, 3.12 to 9.87 m³/t.

Potential Use : Products from samples 3 to 5 compared favourably with commercial vermiculite.

Identification : Ont. - 5 (Ref. No. 70)

Report - Title : MILLING TESTS ON STANLEYVILLE VERMICULITE

- Author : H.S. Wilson

- No. and Date: *Industrial Minerals Report No. 452, 1957.*

Sample Description : 100 kg of minus 15 cm vermiculite from Stanleyville, 16 km southwest of Perth.

Objective : To evaluate various crushing techniques for the recovery of vermiculite.

Processing : The sample was crushed to 3 cm by jaw crusher and divided into three portions. Each portion was further reduced by stage crushing to 6.7 mm using a Pennsylvanian impact mill, a Sturtevant hammer mill and a Sturtevant rolls crusher. After crushing, each portion was further evaluated by screening at successive sizes down to 150 μ m. Following evaluation, all products were further reduced by rolls crusher, and removal of the gangue was attempted by winnowing, air tabling and electrostatic separation.

Results : The Pennsylvania impactor produced the best product consistent with the greatest amount of gangue reduction and generation of the smallest quantity of fines. Electrostatic separation appeared to be superior to both air tabling and winnowing techniques. Recovery of vermiculite by electrostatic separation was 35 to 45%.

Potential Use : Not applicable.

Identification : Ont. - 6 (Ref. No. 71)

Report - Title : EXFOLIATION OF VERMICULITE FROM TIMISKAMING AREA

- Author : H.S. Wilson

- No. and Date : Industrial Minerals Report No. 59-9, 1959.

Sample Description : Three 2 kg samples containing black vermiculite with quartz, hornblende and feldspar as principal impurities; essentially minus 50 mm in size.

Objective : To recover and evaluate the vermiculite as source material aggregate for lightweight concrete and plaster.

Processing : Samples were crushed to 9.5 mm by jaw crusher and delaminated by rolls crusher. Crusher products were screened at 4.8 mm, 2.4 mm, 1.2 mm, 600 μ m and 300 μ m; each size fraction was exfoliated in a gas-fired kiln at 980°C. Exfoliated vermiculite was recovered by winnowing.

Results : Vermiculite recovery from the three samples was 18, 50 and 37%; only sample 3 showed good exfoliation. Bulk densities for samples 2 and 3 were 368 and 192 kg/m³, respectively, which are above the density values normally specified for concrete (96 to 160 kg/m³) and plaster (120 to 160 kg/m³) aggregate.

Potential Use : Suitable as aggregate for lightweight concrete and plaster.

- Identification : Ont. - 7 (Ref. No. 72)
- Report - Title : EVALUATION OF VERMICULITE FROM CAVENDISH TWP.
PETERBOROUGH CO.
- Author : H.S. Wilson
- No. and Date: *Mineral Processing Test Report 60-55, 1960.*
- Sample Description : Four 5 to 10 kg samples of minus 10 cm ore, each composed of a consolidated plus 4.8 mm fraction and a weathered minus 4.8 mm fraction.
- Objective : To recover and evaluate the vermiculite.
- Processing : Samples were screened on 12.7 and 4.8 mm sieves. The plus 12.7 mm fractions were reduced to 4.8 mm by jaw and rolls crushers; the minus 12.7 plus 4.8 mm fractions were saved as reference samples. The minus 4.8 mm crushed product and the minus 4.8 mm weathered fraction were screened separately at 2.4 mm, 1.2 mm, 840 μ m, 600 μ m and 420 μ m. Each fraction was treated at 980 to 1010°C in a tube furnace to exfoliate the vermiculite, which was recovered by air separation. The minus 420 μ m fraction was discarded.
- Results : The bulk densities of the weathered minus 4.8 mm plus 420 μ m fractions varied from 128 to 272 kg/m³. The bulk densities of the unweathered minus 4.8 mm plus 420 μ m fractions were higher at 160 to 288 kg/m³. The grade of vermiculite was low in all tests except weathered sample 1, when 52% vermiculite was obtained.
- Potential Use : This vermiculite is too fine for use as insulation, but would be of interest as an additive in insulating concrete and plaster.

- Identification : Ont. - B (Ref. No. 73)
- Report - Title : EVALUATION OF VERMICULITE FROM CAVENDISH TWP.
PETERBOROUGH CO.
- Author : H.S. Wilson
- No. and Date: *Mineral Processing Test Report 60-74, 1960.*
- Sample Description : Three additional samples, 5, 6 and 7 (Ref. MPT 60-35, 1960), were received. Samples 5 and 6 were unconsolidated and composed of vermiculite, calcite, quartz and feldspar; sample 7 was similar in composition but in lump form.
- Objective : To recover and evaluate the vermiculite.
- Processing : Sample 7 was crushed to about 10 mm, and all three samples were screened at successive sizes from 4.8 mm to 420 μm . Each fraction was treated in a small tube furnace at 1010 to 1035°C to exfoliate the vermiculite. The vermiculite was recovered from the processed samples by air separation.
- Results : The plus 420 μm portion of sample 5 contained 18% vermiculite and had a density of 144 to 224 kg/m^3 . The minus 420 μm portion of this sample, representing more than 50% of the total sample weight, contained 16% vermiculite and had a density of 176 kg/m^3 .
- Potential Use : These vermiculite samples were fine grained and would be unsuitable for insulation. Sample 5 would be of interest as source material for concrete and plaster aggregate.

Identification	: Oxi. - 9 (Ref. No. 74)
Report - Title	: EVALUATION OF VERMICULITE SAMPLES FROM SUDBURY AREA
- Author	: H.S. Wilson
- No. and Date	: Mineral Processing Test Report 60-93, 1960.
Sample Description	: Two samples A and B from a deposit located 63 km south of Sudbury. One sample was brown and essentially minus 10 mm in size; the other was black and contained several lumps up to 50 mm in size.
Objective	: To recover and evaluate the vermiculite.
Processing	: Samples were reduced by jaw crusher to 10 mm, and both samples were screened at successive sizes from 4.8 mm to 150 μ m. Each fraction was then exfoliated in a small tube furnace at 1065 to 1090°C. The vermiculite was recovered by air separation and examined by binocular microscope.
Results	: Both samples contained a fairly high percentage of coarse material. Sample A contained 23 and sample B, 37% of plus 1.2 mm material; the average vermiculite content was 94 and 60%, respectively.
Potential Use	: The plus 1.2 mm fraction of sample A would probably be of interest for insulation, although its average unit weight, at 168 kg/m ³ , exceeds the nominal 96 to 112 kg/m ³ specification.

Identification	: Oct. - 10 (Ref. No. 75)
Report - Title	: INVESTIGATION OF VERMICULITE-BEARING SAMPLES FROM STANLEYVILLE
- Author	: H.S. Wilson
- No. and Date	: <i>Investigation Report</i> 61-39, 1961.
Sample Description	: Thirty samples of drill core from the 38 to 120 m interval; 70 kg of minus 50 mm composite material from auger holes in the pit floor, and two 7 kg samples of surface material. The core and surface samples averaged 25% and the auger samples, 12% vermiculite.
Objective	: To determine grade and particle size distribution of vermiculite, and to evaluate for use as insulation.
Processing	: Reduction to 6.4 mm by jaw and roll crushers, followed by screening at successive sizes from 2.4 mm to 150 μ m. Each size fraction was exfoliated in an electrically heated tube furnace at 1050 to 1080°C; air separation was employed to recover the expanded vermiculite. Beneficiation also included magnetic, electrostatic and heavy liquid separation.
Results	: In excess of 65% of the contained vermiculite was recovered in the minus 1.2 mm plus 300 μ m fractions following exfoliation. The recovery of 1.7 mm insulation-grade vermiculite, however, was very low at 15%. Magnetic and electrostatic separation were unsuccessful; heavy liquid separation at S.G. 2.80 separated vermiculite and talc from diopside but did not result in a vermiculite concentrate.
Potential Use	: As an aggregate in gypsum plaster.

- Identification : Oat. - 11 (Ref. No. 76)
- Report - Title : BENEFICIATION OF VERMICULITE FROM THE SUDBURY AREA
- Author : R.A. Wyman
- No. and Date: *Investigation Report 61-119, 1961.*
- Sample Description : 540 kg of minus 20 mm ore containing about 15% vermiculite with decomposed granite and sandy clay as the principal impurities.
- Objective : To recover vermiculite for possible use as gypsum plaster aggregate.
- Processing : Hammer mill reduction of a sample to 840 μ m followed by magnetic separation. Comparative grinding of a second sample by pebble mill, rod mill and rolls crusher, followed by screening of crushed products on successive size fractions from 9.5 mm to 300 μ m. Further beneficiation included agglomerate (skin) flotation of minus 2.4 mm plus 300 μ m fraction; flotation of four deslimed sized fractions from minus 2.4 mm to plus 600 μ m; electrostatic separation and wet tabling at minus 1.2 mm plus 300 μ m; and dry tabling at minus 9.5 plus 2.4 mm.
- Results : Magnetic separation tests were not successful, but grinding by rolls crusher followed by screening produced some concentration of the vermiculite. Flotation was not selective since slimes quickly depleted flotation reagents. Electrostatic separation showed some promise, although vermiculite recovery was low.
- Potential Use : Not determined.

- Identification : Ont. - 12 (Ref. No. 77)
- Report - Title : BENEFICIATION OF VERMICULITE FROM STANLEYVILLE
- Author : R.A. Wyman
- No. and Date : *Investigation Report 64-66, 1964.*
- Sample Description : Two 2 t samples from a stockpile at Stanleyville; one sample from the surface, the other from the interior at a depth of 3.5 m.
- Objective : To recover and evaluate vermiculite.
- Processing : A variety of wet and dry processing methods was investigated including:
- Wet**
- Self-grinding of the plus 20 mm fraction in a pebble mill. Products from the self-grinding tests were sized and used for wet gravity concentration testwork; jigging of the minus 4.8 plus 2.4 mm fraction; sizing and drying of products; recovery of vermiculite by winnowing and exfoliation; Humphrey's Spiral treatment of the minus 4.8 mm plus 840 μ m fraction, and wet tabling of the minus 2.4 mm plus 840 μ m, and minus 840 plus 600 μ m fractions.
- Dry**
- Air tabling of minus 4.8 plus 2.4 mm and minus 2.4 mm plus 840 μ m fractions. Differential rolls crushing at 4.8 mm and screening on successive size fractions from 4.8 mm to 210 μ m, followed by air tabling of each fraction down to 600 μ m.
- Results : There was no significant wet concentration of vermiculite; products contained large percentages of 'thin' mica, and exfoliation tests were only moderately successful.
- Dry air tabling following crushing and screening of sized fractions was the most successful, but delamination of the vermiculite before tabling was a recovery prerequisite. Grade and recovery of the products from air tabling varied from 75% vermiculite with a recovery of 66%, to 86% vermiculite with a recovery of only 30%.
- Potential Use : Not determined.

Identification : Ont. - 13 (Ref. No. 78)

Report - Title : EXAMINATION OF VERMICULITE SAMPLES FROM CARGILL TWP.
- Authors : R.K. Collings, H.S. Wilson and R.M. Buchanan
- No. and Date: *Division Report 82-6(IR)*, 1982.

Sample Description : Four grab samples: mica-vermiculite (samples 1 and 2), rock (sample 3) and coarse lumps of micaceous 'books' up to 10 cm in size (sample 4). The samples analyzed 16, 69, 10 and 99% vermiculite, respectively.

Objective : To recover and evaluate vermiculite.

Processing : Stage reduction by jaw crusher to 12.5 mm; screening at 4.8 mm, 1.4 mm, 500 μm and 150 μm followed by exfoliation tests on each size fraction in a stainless steel tube furnace at 950°C; and recovery of vermiculite by air separation.

Results : Samples 1 and 3 were low grade and very fine at 150 to 500 μm , and of little commercial interest. Sample 2 was concentrated mainly in the coarser plus 1.4 mm size fraction and exhibited a bulk density of less than 160 kg/m³. The plus 5 mm portion of sample 4, representing 70% of the sample, was essentially pure vermiculite with a bulk density of 130 kg/m³.

Potential Use : The plus 1.4 mm portion of sample 2 would be of interest for loose insulation and as an additive in concrete and plaster. The plus 5 mm portion of sample 4 would also be of interest, particularly for insulation.

Identification : Ont. - 14 (Ref. No. 79)

Report - Title : RECOVERY OF PHOSPHATE ASSOCIATED VERMICULITE FROM CARGILL TWP.

- Authors : R.K. Collings, S.S.B. Wang and J.M. Lamothe

- No. and Date : *Division Report 85-5(CR)*, 1985.

Sample Description : Two sample lots were received:

- A 30 kg sample containing 'books' of vermiculite up to 100 mm across and 6 to 12 mm thick, associated with 50 to 75 mm silicate grit;
- A 315 kg 'trench' sample containing 50% vermiculite in 'books' measuring 75 x 75 x 10 mm thick, associated with coarse silicate grit.

Objective : To recover vermiculite.

Processing : Differential crushing of the grab sample by jaw and rolls crushers with screening at 9, 6 and 3 mm; air jigging and air tabling with exfoliation and recovery of vermiculite.

Hammer mill reduction of the trench sample with screening at successive sizes from 9 to 0.15 mm; separation of vermiculite on air jigs and tables with exfoliation and recovery of vermiculite by air separation.

Results : Differential crushing and sizing was effective for separating vermiculite from the grit. Vermiculite reported in the plus 1.5 mm fraction, whereas the 'grit' tended to report in the minus 1.5 mm fraction. Recovery of vermiculite from the trench sample was about 87% in three products. The plus 12 mm from the hammer mill grading 93% vermiculite, the minus 12 plus 1.5 mm concentrate from the air jig, 58% vermiculite, and the minus 1.5 plus 0.15 mm concentrate from the air table, 76% vermiculite.

Potential Use : Not determined.

- Identification : Ont. - 15 (Ref. No. 80)
- Report - Title : BENEFICIATION OF STANLEYVILLE VERMICULITE
- Authors : J.M. Lamothe and S.S.B. Wang
- No. and Date: *Division Report 86-18(IR)*, 1986.
- Sample Description : Two samples:
- A 160 kg grab sample from an open pit that was easily crushed by hand. The vermiculite, in 'book' form, was essentially free at 2 mm; minus 2 mm vermiculite was delaminated and contaminated with hematite-goethite.
 - A 35 kg split-core sample (upper and lower sections) essentially composed of thinly banded, finely divided vermiculite in a talcose-schistose rock.
- Objective : To recover and evaluate vermiculite.
- Processing : Various methods of separation were investigated at one or all of the following sizes: minus 2.0 plus 0.6 mm, minus 0.6 plus 0.3 mm, and minus 0.20 plus 0.15 mm. Methods included magnetic, electrostatic, gravity, flotation, crushing, sizing and air tabling of exfoliated vermiculite.
- Results : Flotation was partially successful in concentrating vermiculite, but the best results were obtained with exfoliated products. Air tabling of the grab sample recovered about 80% of the total volume of exfoliated vermiculite.
- Core sample beneficiation of the upper portion of the deposit produced a table concentrate representing 73% of the total volume of vermiculite. The lower portion of the deposit produced a concentrate containing 80% of the exfoliated vermiculite.
- Potential Use : Not determined.

APPENDIX D

SUMMARIES OF OTHER VERMICULITE STUDIES

BRITISH COLUMBIA

Identification : B.C. - 1 (Ref. No. 81)

Report - Title : THE RECOVERY OF VERMICULITE, A SAMPLE FROM PERRY RIVER
- Author : R.G. Williamson
- No. and Date: *Lakefield Research Report 3585, 1988.*

Sample Description : Bulk sample analyzing 70% vermiculite, 10% hornblende and 15% feldspar, with minor biotite, hematite and apatite.

Objective : To produce expanded vermiculite suitable for lightweight aggregate.

Processing : Crushing to minus 6.7 mm, exfoliation of minus 4.8 plus 2.4 mm followed by wet tabling and sink-float separation to produce a vermiculite concentrate.

Results : The vermiculite did not fully expand, and the general appearance was a darker red than the typically normal yellow-brown or grey colour. The bulk densities were also too high.

Potential Use : Not a potential source of vermiculite.